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Lower Devonian Brachiopods from the Fukuji Formation, Central Japan

By

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Abstract

The Lower Devonian brachiopod fauna is described for the first time in Japan. The faunal content of the Fukuji Formation indicates a certain degree of endemism. There are distinguished sixteen forms, of which *Isorthis (Isorthis) fukujiensis*, *Leptostrophia japonica*, and *Eosprifer variplicatus* are newly described.

Übersicht

Die unterdevonische Brachiopoden-Gesellschaftung wird zum ersten in Japan beschrieben. Die Gesellschaftung aus der Fukuji-Formation zeigt eine gewißen Grad von Endemismus. Es werden sechzehn Formen, von dennen *Isorthis (Isorthis) fukujiensis*, *Leptostrophia japonica* und *Eospirifer variplicatus* neu beschrieben werden.

Introduction

Since the discovery of the Lower Devonian Tobigamori Formation in the Kitakami Massif, Northeast Japan (YABE and NODA, 1933), the Middle Paleozoic strata have been found in several regions in Japan. Their brachiopod faunas have been described by several workers; from the Upper Devonian Tobigamori Formation by YABE and NODA (1933), TACHIBANA (1953), HAYASAKA and MINATO (1954), and NODA and TACHIBANA (1959); from the Middle Devonian Nakazato Formation by SUGIYAMA (1942) and OKUBO (1956); from the Upper Devonian Ainosawa Formation by HAYASAKA and MINATO (1954); from the Middle and Upper Silurian rocks in Kyushu by HAMADA (1962); from the Middle Silurian rocks in Shikoku by NODA (1964). No brachiopod of early Devonian age, however, has been described in Japan until today.

The Fukuji Formation of the Hida Massif, Central Japan, is known to yield a rich fauna of Early Devonian age. Previously favositoids (KAMEI, 1955; HAMADA, 1959d) and trilobites (KOBAYASHI and IGO, 1956; KOIZUMI and KAKEGAWA, 1970; OKAZAKI, 1974; KOBAYASHI and HAMADA, 1977) were described. The formation also bears a rich fauna of brachiopods, but they have been left undescribed. In this paper, stratigraphy and age of the Fukuji Formation are mentioned, then the brachiopods from the formation are described, and several interesting species are examined in some detail. Finally some faunal consideration is given in comparison with the Chinese faunas.

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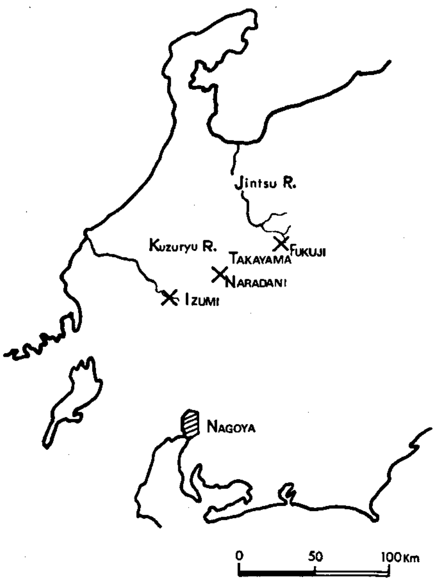

Figure 1. Index map.
×: Localities of the Middle Paleozoic rocks in the Hida Massif.

Stratigraphy of the Fukuji Formation

Fukuji is located in the southern part of the Hida Massif (Figure 1), where the Fukuji Formation is exposed at the southern foot of Mt. Sorayama as a block jammed in the Circum-Hida Tectonic Zone together with younger Paleozoic rocks and intrusive rocks such as serpentinite (Figure 2).

The Fukuji Formation is bounded on the north by the Carboniferous Ichinotani Formation with faults, and on the south by the Permian Sorayama Formation again with faults. The faults which set up the boundaries are nearly in east-west direction. The eastern margin of the formation is covered with the terrace deposits of

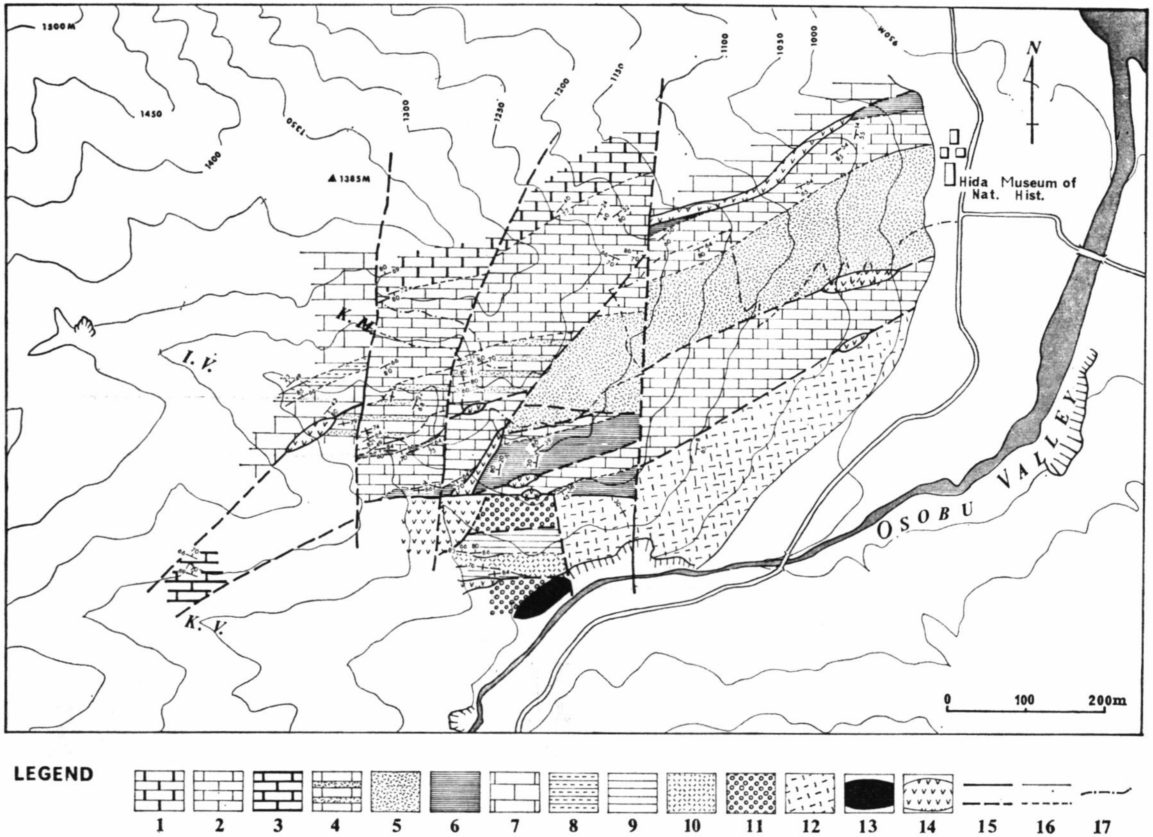

Figure 2. Geological map of the Fukuji District.
1–6 Devonian Fukuji Formation 1. brown limestone 2. gray limestone 3. black limestone 4. alternation of tuff and limestone 5. tuff 6. shale 7–8 Carboniferous Ichinotani Formation 7. limestone 8. red shale 9–10 Carboniferous Mizuyagadani Formation 9. shale 10. schalstein 11–12 Permian Sorayama Formation 11. conglomerate 12. schalstein 13 serpentinite 14 dyke rocks 15 faults 16 boundaries of beds 17 trails *I.V.* Ichinotani Valley *K.V.* Kanajiro-sako Valley *K.M.* Kiuma-michi (trail for wood cutters).

Hirayu River flowing along the eastern foot of Mt. Sorayama. The western limit of the distribution is not determined because of dense vegetation to the west beyond the Kanajiro-sako Valley. The outline of the distribution is rectangular, having longer sides in the east-west direction, which coincides with the general trend of the formation. The formation is considered to be homoclinic in structure with nearly vertical dip, becomming younger to the south. It is further cut into several small blocks by faults striking almost northward. The stratigraphic successions obtained in some good outcrops are shown in Figure 3.

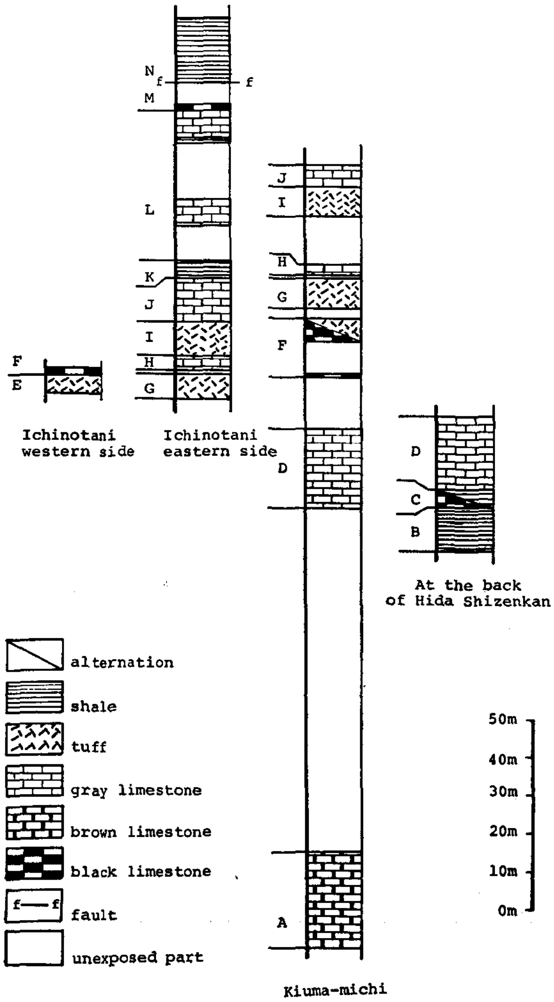

Figure 3. Columnar sections of the Fukuji Formation.

The formation has a total thickness of about 260 m, and is divided into three members. The Lower Member consists mainly of limestone with a considerable amount of shale, the Middle Member of coarse plagioclase tuff with a small amount of limestone, and the Upper Member of limestone and shale. The three members are further divided into 14 beds on the basis of their lithology (OHNO, 1974MS). KAMEI (1955) formerly divided the formation into 11 beds. A comparison between the present division and latter one is given in Table 1. The Beds A and B are newly found, and the Beds C and D are considered to correspond to the Bed 1 of KAMEI (1955).

Table 1. Comparison of the stratigraphic divisions of the Fukuji Formation.

KAMEI (1955)		OHNO (1974MS)	
Upper limestone and shale Member	Bed 11	Bed N	Upper Member
	Bed 10	Bed M	
	Bed 9	Bed L	
	Bed 8	Bed K	
	Bed 7	Bed J	
Middle tuff Member	Bed 6	Bed I	Middle Member
	Bed 5	Bed H	
	Bed 4	Bed G	
	Bed 3	Bed F	
	Bed 2	Bed E	
Lower limestone Member	Bed 1	Bed D	Lower Member
		Bed C	
		Bed B	
		Bed A	

Geologic Age of the Fukuji Formation

Several different opinions have been expressed on the age of the Fukuji Formation since the first discovery by KAMEI (1949), but recent investigations throw light on the problem. Before going further, it must be noted that the following discussion is limited to the Beds B to N, since the Bed A differs considerably from any other bed of the formation in its faunal composition as well as its lithology. The age of the Bed A should be studied in the future.

From the Bed D, OHNO (1974MS) obtained a number of specimens of conodonts which are all identified as *Icriodus rectangularis* CARLS et GANDL, or *Icriodus huddlei curvicauda* CARLS et GANDL, both being characteristic of the Siegenian to the Emsian. From the Middle Member of the formation, KAMEI *et al.* (1973) reported an occurrence of solitary coral *Rhizophyllum enorme* ETHERIDGE, which is also characteristic of the Siegenian to the Emsian. KOBAYASHI and HAMADA (1974b) studied the trilobite fauna, and suggested the Siegenian to the Early Eifelian age for the formation.

More recently IGO *et al.* (1975) reported the occurrence of *Icriodus woschmidti woschmidti* ZIEGLER and *Spathognathodus remscheidensis* ZIEGLER from the Bed D, and considered the age of the formation as the Early Gedinnian. But the specimens illustrated by them are poorly preserved, and the present author hesitates to follow their opinion about the age.

In summary, the Fukuji Formation is most probably the Siegenian to the Emsian in age.

Brachiopods of the Fukuji Formation

The brachiopod fauna of the Fukuji Formation was studied based on some 300 samples. A few hundreds of samples are collected by the present author, mainly from the Bed B which is the most fossiliferous bed in the formation. Other beds seldom yield well preserved specimens. Messers Y. ISHIGURO, T. ONO, K. KITAGAWA, K. KITO H. KOIZUMI, Y. TANAKA, S. WAKATA, and S. YAMAGOSHI have provided the additional samples which have been also collected mainly from the Bed B. All the materials illustrated in the present paper are registered and deposited in the Departmentof Geology and Mineralogy, Kyoto University.

The samples examined were prepared according to prevailing methods. Impressions were made from the molds with silicon rubber and natural rubber, in order to examine internal structures and external fine ornamentations of the shells. When natural molds were not available, the molds were prepared by dissolving the calcite shells in shaly matrix with dilute hydrochloric acid. The internal structures were also examined with a serial grinding and peel method.

Table 2. Stratigraphic distribution of brachiopods in the Fukuji Formation.

beds / taxa	A	B	C	1 D	2 E	3 F	4 G	5 H	6 I	7 J	8 K	9 L	10 M	11 N
1. *Crania* sp.		+												
2. *Isorthis* (*Isorthis*) *fukujiensis* sp. nov.		+											+	
3. "*Leptaena*" sp.		+												+
4. *Cymostrophia* sp.		+												
5. *Leptostrophia japonica* sp. nov.		+												
6. "*Schuchertella*" sp.		+									+		+	
7. Chonetacea gen. et sp. indet.		+												
8. Gypidulinae gen. et sp. indet.			+											
9. Rhynchonellida gen. et sp. indet. a		+												
10. Rhynchonellida gen. et sp. indet. b					+									
11. Atrypidae gen. et sp. indet. a		+												
12. Atrypidae gen. et sp. indet. b		+												
13. *Eospirifer variplicatus* sp. nov.		+												+
14. *Howellella* sp. a			+											
15. *Howellella* sp. b		+												
16. Suessiacea gen. et sp. indet.		+												

Table 2 represents sixteen forms of brachiopods from the Fukuji Formation among six orders; Acrotretida, Orthida, Strophomenida, Pentamerida, Rhynchonellida, and Spiriferida. Eight genera recognized from the formation belong to following seven families; Craniidae, Dalmanellidae, Leptaenidae, Stropheodontidae, Schuchertellidae, Eospiriferidae, and Delthyrididae. In addition, the families Pentameridae and Atrypidae are represented by one form to the former and two forms to the latter, without generic assignment. Three new species are described later; *Isorthis* (*Isorthis*) *fukujiensis*, *Leptostrophia japonica*, and *Eospirifer variplicatus*. KAMEI (1961, Pl. 1, fig. 5) illustrated an internal mold of a dorsal valve from the Fukuji Formation, identifying as *Elytha* or *Undispirifer*, neither of which, however, is found in the present material. The illustrated specimen may be identified as *Howellella* sp. or *Eospirifer variplicatus*.

Discussion

The materials examined presently are not sufficient enough to clarify the whole picture of the fauna. Nevertheless several interesting results can be pointed out.

1) Two of the three new species described here, *Isorthis* (*Isorthis*) *fukujiensis* and *Eospirifer variplicatus*, differ remarkably from other species of the related taxa in morphology. *Isorthis* (*Isorthis*) *fukujiensis* is considered to be one of the youngest representatives of the subgenus. Only the morphology of the muscle fields indicates that this specimen belongs to *Isorthis* (*Isorthis*), although many other features are different from those in other species of the subgenus (see Table 3). The subfamily Eospiriferinae comprises six genera which are distinguished from each other by their plication types (BOUCOT, 1962). *Eospirifer variplicatus* is characterized by the peculiar plication type as will be mentioned later. This type of plication has not been known among other species and genera of the subfamily. The presence of these species indicates a considerably endemic character of the present fauna.

The presence of *Leptostrophia japonica*, however, provides another kind of information on the faunal characteristics. This species is characterized by different types of surface ornamentation on each valve, that is, parvicostellate ornamentation on ventral valve, and finely costellate one on dorsal valve. *Leptostrophia* provided with this type of ornamentation is known from U. S. A. (JOHNSON, 1970) and Australia (CHATTERTON, 1973). Since it is difficult to consider that such a peculiar combination of ornamentation was evolved independently, these three must have been related to each other. The presence of *Leptostrophia japonica* therefore indicates that the brachiopod fauna of the Fukuji Formation is not completely endemic.

2) Comparison between the Fukuji fauna and faunas in South and North China reveals also a considerably isolated condition of the Japanese fauna. Although in the neighbourhood of Japan, the Devonian strata distribute in USSR, Mongolia, and

China, the comparison is made only between the Fukuji fauna and those in China, because of the lack of available data on the former two regions at this moment. Although many of brachiopods in the Fukuji Formation are left without specific identification, it is clear that all the forms of the formation differ from species of either South or North China, that is, the Fukuji Formation has no species common to the faunas of those regions. In addition to this fact, the Fukuji fauna has little in common with those in South or North China, when compared in generic level.

a) Study on the Devonian brachiopods in South China was initiated by DE KONINCK (cited in GRABAU, 1931), and many brachiopods were described thereafter (GRABAU, 1931, 1933; YANG and WANG, 1955; HOU, 1963, etc.). Recently WANG, YU *et al.* (1974), WANG, LIU *et al.* (1974), HOU and XIAN (1975) reexamined the Devonian rocks of South China and confirmed a wide distribution of the Lower Devonian marine strata. According to HOU and XIAN (1975), the Lower Devonian strata of South China are divided into three formations in descending order:

The Szepai Formation:	Upper Emsian
The Yukiang Formation:	Upper Siegenian to Lower Emsian
The Nahkaoling Formation:	Gedinnian to Lower Siegenian

From the Nahkaoling Formation, fifteen brachiopod genera are known (WANG, YU *et al.*, 1974; HOU and XIAN, 1975), among them only *Howellella* is evidently the common genus to the Fukuji fauna. Even if a chonetacean species from the Fukuji Formation is congeneric with the *Chonetes* from the Nahkaoling Formation, only two genera are common to the both formations.

From the Yukiang Formation thirty one genera are reported (YANG and WANG, 1955; WANG, 1956 b; HOU, 1963 a; WANG, LIU *et al.*, 1974; WANG, YU *et al.*, 1974; HOU and XIAN, 1975). Three genera, *Cymostrophia*, *Leptostrophia*, and *Howellella* are also found in the Fukuji fauna.

From the Szepai Formation nine genera are recognized (WANG, LIU, *et al.*, 1974; HOU and XIAN, 1975). None of them is, however, found in the Fukuji fauna.

b) In North China the Lower Devonian brachiopods are only known from the Nichiuho Formation. NONAKA (1944) made a preliminary study on the fauna. Recently HAMADA (1971) reexamined NONAKA's collection, describing thirty species among twenty nine genera, and considered the age of the fauna as the Siegenian to the Emsian. Only three genera, *Leptostrophia*, "*Schuchertella*", and *Howellella* are common to the Fukuji and Nichiuho formations.

Summary

The Lower Devonian brachiopods of the Fukuji Formation comprise sixteen

forms and indicate a certain degree of endemic condition of the fauna.

Eospirifer variplicatus and *Isorthis* (*Isorthis*) *fukujiensis* in the Fukuji Formation differ considerably from other species of related taxa respectively. The faunal composition of the formation, in generic level as well as specific level, is also different from those in China. These facts indicate that the fauna of the Fukuji Formation developed in an isolated condition, although some communication with faunas of other regions is suggested, for example, by the presence of *Leptostrophia japonica*. The process of the establishment of this fauna should be clarified in the future study.

Systematic Descriptions

Order Acrotretida KUHN, 1949

Suborder Craniidina WAAGEN, 1885

Superfamily Craniacea MENKE, 1828

Family Craniidae MENKE, 1828

Genus *Crania* RETZIUS, 1781

Crania sp.

Plate 1, figs. 8–9; Plate 2, figs. 4, 10

MATERIAL: 5 specimens are available.

DESCRIPTION:

Dorsal exterior: Valve is conical, with its apex located medially and at 2/5 to 3/5 of the valve length, and sub-circular in outline. Sometimes valve margin is inwardly curved at postero-lateral and antero-median portions (Plate 1, figs. 8, 9). Surface ornamentation is uncertain except the numerous minute tubercles structures along the valve margin.

Ventral interior: Ventral valve is irregular in shape. The whole margin of the interior is fringed by a continuous shallow groove with U-shaped cross-section, which accomodates the peripheral ridge on the interior of dorsal valve (Plate 2, fig. 10b). The groove is associated with a continuous and weak ridge along its inside. Muscle scars and other features are uncertain.

Dorsal interior: Shell periphery is elevated. 2 pairs of elevated muscle scars are observed (Plate 1, figs. 8, 9). One pair occupies postero-lateral portion of the valve, consisting of 2 trapezoidal platforms with their basal sides parallel to the valve margin. The other pair is located near the apex of the valve. Each muscle scar of this pair consists of two small platforms; the more medially located one is with longitudinally elongated elliptical outline, and more laterally located one is with irregular outline. On the antero-lateral portion, scar of pinnate vascula lateralia is weakly impressed. Sometimes an elongate ridge is observed on the antero-median portion of the valve interior (Plate 1, fig. 9).

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31001	dorsal interior	16.9	15.5*	4.1
JP31002	dorsal interior	15.6	15.9	3.9
JP31003	dorsal exterior	13.1	13.8*	3.9

Measurements are all in mm: *: twiced value from the measurement on a half side of the valve in regard of the plane of symmetry.

Order Orthida SCHUCHERT et COOPER, 1932
Suborder Dalmanelloidea MOORE, 1952
Superfamily Dalmanellacea SCHUCHERT, 1913
Family Dalmanellidae SCHUCHERT, 1913
Subfamily Isorthinae SCHUCHERT et COOPER, 1931
emended WALMSLEY et BOUCOT, 1975
Genus *Isorthis* KOZLOWSKI 1929, emended WALMSLEY, 1965
Subgenus *Isorthis* (*Isorthis*) KOZLOWSKI, 1929
emended WALMSLEY et BOUCOT, 1975
Isorthis (*Isorthis*) *fukujiensis* sp. nov.
Plate 1, figs. 1–7; Plate 2, figs. 1–3, 5–9, 11–14

HOLOTYPE: JP31006 (Plate 1, fig. 2).
MATERIAL: About 80 specimens are available.

DIAGNOSIS: Shell large, with gently sulcate dorsal valve. Muscle fields are confined to postero-median portion and small on both valve interiors. The cardinal process with bilobed myophore. Sockets with faint fulcral plates, without socket pads.

DESCRIPTION:

Ventral exterior: Valve is convex, transversely elongate elliptical to shield shape in outline, with sharply rounded cardinal extremities and slightly rounded to nearly straight anterior margin. The valve length is about 9/10 of the maximum width, which is located at about 1/3 of the valve length from the beak. The length of the hinge line is about 1/3 to 1/2 of the valve width. The umbo projects only about

1/10 of the valve length beyond the hinge line posteriorly and has an apical angle of about 100 degrees. In anterior view the valve has subtriangular outline with a gently sulcate anterior commisure (Plate 1, fig. 2e). The valve thickness is about 1/5, and the width of the sulcation is about 1/3, of the valve width. Faintly concave interarea is apsacline, bounded with sharp lateral margins, and finely striated transversely. The delthyrium is small and open, with delthyrial angle of about 60 degrees. Surface ornamentation is parvicostellate. The costellae increase in mumber by insertion, and about 4 to 6 costellae occur per 1 mm width at 5mm from the beak. In well preserved specimens densely packed concentric, fine and scaly ridges occur on the bottom of the grooves between costellae.

Dorsal exterior: Valve is as strongly convex as the ventral valve, with transversely elongate elliptical to shield shape outline. The length is about 4/5 of the maximum width, which is located a little posterior to the mid-length of the valve. The velve thickness is about 1/5 of the valve width. The umbo is very small. A shallow, gently rounded sulcus is present, well defined posteriorly, becoming shallower anteriorly (Plate 1, figs. 2b, d, e). The interarea is very low, orthocline, bounded with sharp lateral margins. Notothyrium is open, enclosing at about 90 degrees, and posteriorly filled by the myophore of the cardinal process. Surface ornamentation is identical to that of the ventral valve.

Ventral interior: The ventral muscle field is elongately sub-pentagonal and occupies median 1/5 and posterior 1/3 of the valve. A wide median ridge with flat roof occupies about median 3/10 and posterior 4/5 of the muscle field, elevating anteriorly, and ending in steeply inclined trapezoidal plane. A pair of weakly divergent diductor tracks with **U**-shaped cross-section bounds the median ridge. A pair of a little divergent dental plates supports small teeth, and bounds the diductor tracks laterally, ending at or a little anterior to the anterior end of the tracks. Along the valve margin crenulations are present. The crenulations consist of ridges of two different magnitudes. The stronger ridges are distributed along the shell margin with wide interspaces, and numbered about 5 per 5 mm width, and 0 to 3 weaker, but similar shaped ridges are inserted between them. Each ridge bears on its top one shallow groove with **V**-shaped cross-section, which deepens anteriorly (Figure 4). In about half number of the shells, genital markings are present, consisting of small, slender tubercles distributed on the postero-lateral portion of the valve. They occur more often in larger shells than smaller ones.

Dorsal interior: The myophore of the cardinal porcess is bilobed, and the top of each lobe is deeply crenulated transversely (Figure 5). The brachiophores project antero-laterally with the angle subtended between them of about 80 degrees. The brachiophore bases extend anteriorly about 1/4 of the valve length, bounding the muscle field postero-laterally. A pair of small fulcral plates is present, which is not supported by socket pads.

Figure 4. *Isorthis (Isorthis) fukujiensis.* Sketch of marginal crenulations on a ventral interior, based on sample JP31013. Bar represents 5 mm.

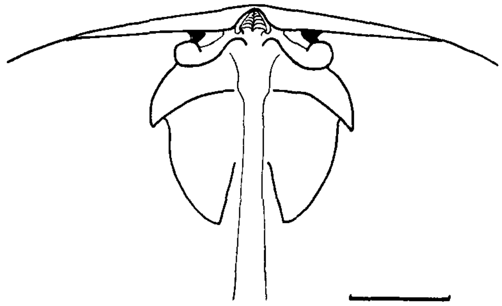

Figure 5. *Isorthis (Isorthis) fukujiensis.* Reconstruction of posterior part of dorsal interior. Note the bilobed cardinal process and small fulcral plates (solid black). Bar represents 5 mm. Owing to the curvature of the shell, the length of the posterior pair of muscle field is apparently shorter than that of the anterior pair.

The sub-pentagonal muscle field occupies about 2/5 of the valve length, and about median 3/10 of the valve width with elevated margins, divided by weak round median ridge into a pair of scars. The median ridge extends anteriorly about 3/5 of the valve length. The scar is further divided transversely in larger shells, and results in quadripartite condition. The width of the posterior pair is always greater than that of the anterior pair, and the length of the posterior pair is usually greater than that of the anterior pair. The floors of the posterior pair gradually elevate anteriorly and end in nearly straight step, the edge of which is transversal in direction. The anterior pair of the muscle scars also elevates anteriorly. Along the valve margin, crenulations are present, consisting of low round ridges, which are numbered about

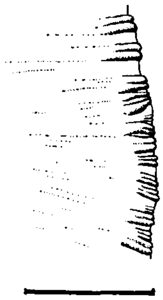

Figure 6. *Isorthis (Isorthis) fukujiensis.* Sketch of marginal crenulations on a dorsal interior, based on sample JP31023. Bar represents 5 mm.

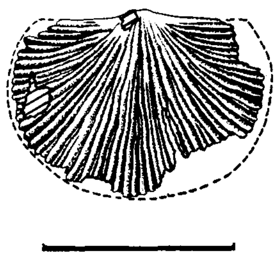

Figure 7. *Isorthis (Isorthis) fukujiensis.* Sketch of a juvenile dorsal valve, based on sample JP31008, showing symmetrical branching pattern of costellae on the median part. Bar represents 5 mm.

14 per 5 mm width and separated from each other by narrow interspaces (Figure 6). Genital markings are occasionally present on the postero-lateral portions of the valve.

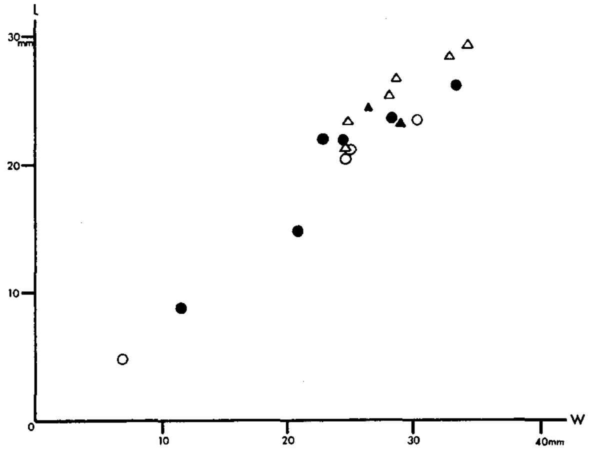

Figure 8. *Isorthis (Isorthis) fukujiensis.* Size distribution. L: length, W: width of valve, open triangle: ventral exterior, solid triangle: ventral internal mold, open circle: dorsal exterior, solid circle: dorsal internal mold.

REMARKS:

On one small dorsal valve (JP31008, Plate 1, fig. 3; Figure 7), the surface ornamentation is well preserved. On the median part the costellae are arranged symmetrically in regard of the plane of symmetry.

Ontogenic variations are observed in dorsal valve interior. Morphologies of brachiophore bases, fulcral plates and marginal crenulations are stable, but that of the muscle scars and median ridges gradually change throughout ontogeny. In juvenile shells, muscle field is not thickened, and is not clearly defined, except for postero-lateral margins bounded by brachiophore bases (Plate 2, fig. 12). Then the antero-lateral boundaries of the muscle field become thick (Plate 2, figs. 8, 11). Following the above stages, the antero-median margins of the field become defined through the thickning of this part of the field. Between the median ridge and the antero-median boundaries of the muscle field, narrow depressions with flat bottoms are left. At this stage, muscle field still remains in bi-partite condition (Plate 2, fig. 13). Finally the posterior part of muscle field becomes thickened, and the muscle field becomes quadripartite condition (Plate 2, figs. 2, 9). The median partition of the dorsal interior first appears as a broad, low and round deflection, which may only reflect the sulcus on the exterior of the valve (Plate 2, figs. 8, 12). The median ridge, which is formed by the differential thickening of the median part of the valve interior, appears later, as the broad deflection disappears gradually.

COMPARISON:

WALMSLEY and BOUCOT (1975) made a comprehensive study on the subfamily Isorthinae. They recognized in the subfamily 2 genera *Isorthis* and *Levenea*, and further divided the former genus into 5 subgenera, *Isorthis* (*Tyersella*), *I.* (*Protocortezorthis*), *I.* (*Ovalella*), *I.* (*Arcualla*), and *I.* (*Isorthis*), based mainly on the morphology of the muscle scars. The morphology of the muscle scars of the presently described species indicates that it belongs to subgenus *Isorthis* (*Isorthis*). WALMSLEY and BOUCOT (1975) assigned three species to the subgenus. Comparison is made with those three species. As the original descriptions of *Isrothis* (*Isorthis*) *neocrassa* (NIKIFOROVA) and *I.* (*I.*) *szajnochai* KOZLOWSKI are not at present author's hand, comparison is made, based on the descriptions in WALMSLEY and BOUCOT (1975). As stated below, the presently described species is not closely related to other species of the subgenus (Table 3). *Isorthis* (*Isorthis*) *fukujiensis* sp. nov. has the largest shell and the smallest muscle fields.

Isorthis (*Isorthis*) *neocrassa* (NIKIFOROVA) (WALMSLEY and BOUCOT, 1975, p. 53) resembles to *I.* (*I.*) *fukujiensis* in having bilobed cardinal process in dorsal valve,

Table 3. Comparison of important features of species of the subgenus *Isorthis* (*Isorthis*).

features / species	sulcus on dorsal valve	cardinal process	sockets	ventral valve		dorsal valve	
				Wm/W	Lm/L	Wm/W	Lm/L
Isorthis (*Isorthis*) *neocrassa*	nonsulcate	bilobed	supported on socket pads	1/3°	1/2°	1/3°	1/2°
Isorthis (*Isorthis*) *clivosa*	weakly sulcate	non-lobed	supported on socket pads	1/4*	3/5*	1/3**	1/2**
Isorthis (*Isorthis*) *szajnochai*	non-sulcate	non-lobed	with small fulcral plates or socket pads	1/4°	1/2°	1/3°	1/2°
Isorthis (*Isorthis*) *fukujiensis*	sulcate	bilobed	with small fulcral plates, but without socket pads	1/5	1/3	1/3	2/5

*: measured from the illustrations in the Plate of the original description (WALMSLEY, 1965).
**: quoted from the original description (WALMSLEY, 1965).
°: quoted from the descriptions in WALMSLEY and BOUCOT, 1975.
Wm/W: ratio of width of muscle field to valve width.
Lm/L: ratio of length of muscle field to valve length.

but differs in non-sulcate dorsal valve, and the sockets supported on socket pads. *Isorthis* (*Isorthis*) *clivosa* WALMSLEY (WALMSLEY, 1965, p. 471, Pl. 61, figs. 31–38; Pl. 62, figs. 1–2) has sulcate dorsal valve, but the sulcation is weaker than that of *I.* (*I.*) *fukujiensis*. The former is also distinguished from *Isorthis* (*Isorthis*) *fukujiensis* in well marked genital markings in the ventral valve, non-lobed bulbous cardinal process, and the median ridge which narrows between anterior pair of adductor impressions, sockets supported on socket pads in the dorsal valve. *Isorthis* (*Isorthis*) *szajnochai* KOZLOWSKI (WALMSLEY and BOUCOT, 1975, pp. 54–55, Pl. 1, figs. 5–8) resembles only in the general shape of the muscle fields and in having, but not invariably, small fulcral plates. The species differs from the new species in more globose shell, non-lobed cardinal process in the dorsal valve, and round median ridge in the ventral muscle field.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31005	ventral exterior	23.4	24.9	5.3
JP31006	ventral exterior	21.5	24.6	4.7
JP31007	ventral exterior	25.4	28.3	7.0
JP31016	ventral exterior	28.8	33.7	5.0
JP31017	ventral exterior	29.3	34.4	5.8
JP31018	ventral exterior	26.8	28.8	7.5
JP31005	dorsal exterior	21.2	24.9	5.0
JP31006	dorsal exterior	20.5	24.6	4.8
JP31027	dorsal exterior	23.5	30.3	7.2

Measurements are in mm.

Order Strophomenida ÖPIK, 1934

Suborder Strophomenidina ÖPIK, 1934

Superfamily Strophomenacea KING, 1846

Family Leptaenidae HALL et CLARKE, 1894

Genus *Leptaena* DALMAN, 1828

"*Leptaena*" sp.

Plate 3, fig. 1

MATERIAL: A few specimens are available.

DESCRIPTION:

The ventral valve is convex, and composed of a flat, transversely elongate, heptagonal visceral disc, a pair of concave ears, and a trail. Anterior margin of the visceral disc bends abruptly at about 90 degrees to the trail (Plate 3, fig. lb). The visceral disc is about 1.35 times as long as the length of the trail.

Muscle field in the ventral interior is fan-shaped, elevating anteriorly, and occupying posterior 2/5 and median 1/7 of the visceral disc. A continuous muscle bounding ridge surrounds the lateral and anterior margins of the muscle field. The median 1/3 of the scar is occupied by a pair of adductor scars, which form gentle ridges with roundly **U**-shaped cross-section and separated medially by a narrow groove with **V**-shaped cross-section. A pair of adductor muscle scars is bounded laterally by a pair of flat diductor muscle scars. A pair of ears is divided from the visceral disc by narrow ridges which initiate from the hinge line at about 1/3 of the half width of the valve from the midpoint of the hinge line, extending anterolaterally, and gently incurving medially. The angle subtended between the ridge and the lateral part of the hinge line is about 70 degrees.

Morphology of the dorsal valve and its interior is unknown.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31028	ventral internal mold	23.2	47.2*	9.1

Measurements are in mm. *: twiced value from the measurement on a half side of the valve in regard of the plane of symmetry.

Family Stropheodontidae CASTER, 1939

Subfamily Stropheodontinae CASTER, 1939

Genus *Cymostrophia* CASTER, 1939

Cymostrophia sp.

Plate 3, figs. 2–6; Plate 4, figs. 1–3

MATERIAL: 15 specimens are available.

DESCRIPTION:

Ventral exterior: Valve is hemi-circular in outline, and the width is a little greater than the length. The maximum width is along the straight hinge line. Poorly preserved cardinal margins are weakly mucronate with incurved posterolateral margins. Lateral and anterior margins are gently rounded. Valve is strongly convex, sometimes with almost semi-circular profile in lateral view; usually more strongly convex in posterior part than in anterior part. Mucronate cardinal margins are slightly concave in anterior view. Umbo with broad apical angle projects a little behind the hinge line. Interarea is flat and narrow, nearly orthocline. Deltidial structures are unknown. Fine ornamentation is parvicostellate with radial fine costellae separated from each other by 3 to 7 fine capillae. Costellae increase in number by implantation and new costellae are implanted between preceding ones at least 3 times during the growth of the shell. About 10 costellae per 1 cm are numbered parallel with, and 1 cm from, the hinge line. Wavy concentric, interrupted rugae are present on posterior 1/6 to 2/5 portion of valve. Fine concentric, interrupted growth lines numbered about 5 to 9 per 1 mm are present between costellae on the remainder of valve where rugae are absent crossing with fine capillae to give grid-like patterns.

Dorsal exterior: Valve is hemi-circular with long hinge line. The maximum width is located along the hinge line. Valve is gently concave with curvature more gentle than that of ventral valve; more strongly concave in posterior portion than in anterior portion. Interarea is catacline. Surface ornamentation is like that of ventral valve.

Ventral interior: Hinge line is ornamented with denticles which number about 4 to 5 per mm. Denticulate part occupies less than half of the length of the hinge line. The cardinal process pits are separated by ventral process. Ventral process bifurcates anteriorly to form a pair of antero-laterally curving ridges which fuse with postero-lateral margins of adductor scars (Figure 9).

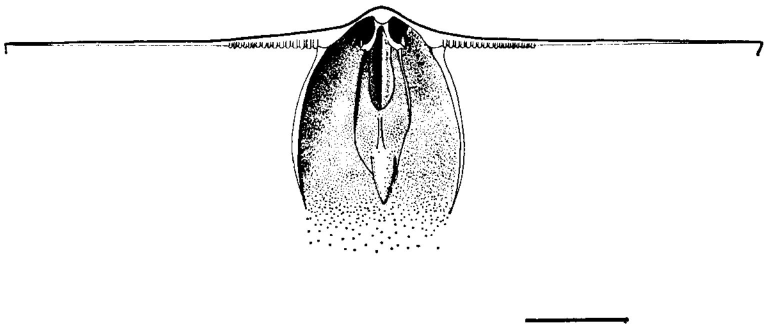

Figure 9. *Cymostrophia* sp. Reconstruction of ventral interior. Bar represents 5 mm.

Muscle field occupies postero-median part of the valve and is longitudinally or transversely elongate sub-circular or, sometimes, gourd-shaped in outline. When the outline is gourd-shaped, the field is waisted near its midlength. Adductor scars have a longitudinally elongate elliptical outline. They are inserted slightly below the level of the adjacent floor of the posterior part of the muscle scar and medially divided by a narrow groove with **V**-shaped cross-section. A pair of semi-flabellate diductor scars borders the adductor scars antero-laterally and is divided by median ridge, which gradually becomes higher anteriorly and ends abruptly. Low acute muscle bounding ridge is prominent posteriorly, but gradually merges in the valve floor anteriorly. Anterior end of diductor scars are not clearly distinguishable. On ears several narrow and shallow grooves are faintly impressed, running subparallel to hinge line and sometimes bifurcating to the lateral margin. These are probably impressions of vascula genitalia.

Dorsal interior: Cardinalia consists of posteriorly directed and bilobed cardinal process and a pair of widely divergent socket ridges. Adductor muscle scars are located on the postero-median part of the shell, divided by median ridge, bounded by a pair of arcuate and anteriorly converging round ridges at least postero-laterally.

REMARKS:

Denticles occupy 1/3 to 1/2 of the hinge line, and the ventral muscle scar occupies posterior 1/3 and median 1/2 of the valve interior. But these figures were smaller originally, because the samples treated here have thin shells, and their cardinal extremities and shell margins are damaged to a certain degree.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31029	ventral exterior	27.8	33.6*	10.3
JP31033	ventral internal mold	21.0	28.7*	8.0
JP31031	dorsal external mold	30.6	38.6	10.8

Measurements are in mm. *: twiced value from the measurement on a half side of the valve in regard of the plane of symmetry.

Subfamily Leptostrophiinae CASTER, 1939

Genus *Leptostrophia* HALL et CLARKE, 1892

Leptostrophia japonica sp. nov.

Plate 4, figs. 4–10; Plate 5, figs. 1–5

HOLOTYPE: JP31035; a ventral valve (Plate 4, fig. 6).

MATERIAL: 15 specimens are available.

DIAGNOSIS: Shell with parvicostellate ornamentation on ventral valve, and finely costellate ornamentation on dorsal valve.

DESCRIPTION:

Ventral exterior: Valve is almost plane to slightly convex, transversely elongate sub-rectangular in outline with acutely round cardinal margins and gently round antero-lateral margins. The maximum width is located at a little anterior to hinge line. The interarea is narrow, apsacline, with broad apical angle. The delthyrium is open, with delthyrial angle of about 60 degrees, and apically covered with small, slightly convex pseudochilidium. Ornamentation is parvicostellate. Delayed costae, which are absent on postero-median small portion, become obvious marginally. They curve gently posteriorly on postero-lateral portion of the valve. They are separated by broad interspaces. Marginally one or a few costae are implanted between preceding ones. Each interspace is covered with a few very faint lirae. The postero-median portion of the valve, where costae are absent, are sometimes covered with very fine radial lirae. Concentric rugae variably develop, which sometimes cover only postero-lateral portions, and sometimes also lateral and anterior margins.

Dorsal exterior: Valve is almost plane to slightly concave. The outline is similar to that of ventral valve. Interarea is very narrow, and anacline, medially interrupted by small convex chilidium. Ornamentation consists only of fine lirae, which radiate from the umbo, and increase in number anteriorly. About 30 lirae are numbered per 5 mm parallel with and 5 mm from the hinge line. Concentric rugae develop on lateral and anterior portions of valve surface.

Ventral interior: Denticles are located medially, occupying about 2/5 to 3/5 of the lenght of the hinge line, but because cardinal extremities are not well preserved, the original proportion was smaller. Faint ventral process projects anteriorly from the posterior extremity of umbonal cavity, but is interrupted anteriorly by adductor scars. The muscle field is triangular, occupies posterior 1/2 to 3/5, and median 1/3 of the valve interior, well impressed posteriorly, but blended imperceptibly with the valve floor anteriorly. The postero-lateral margins of muscle field are bounded by pustulate linear bounding ridges. These lateral bounding ridges extend anteriorly about 2/5 of the length of the muscle field, or about 1/5 to 1/3 of the valve length, diverging from each other at about 64 to 78 degrees. The adductor field consists of a pair of elongately fusiform platforms, which are located on postero-median portion of muscle field and become contact with each other near their midlength. The ventral process is low and round, ends anteriorly at the point of contact of adductor scars, and a narrow round median ridge extends from this point anteriorly to some extent. A pair of diductor scars surrounds adductor scars antero-laterally. The floor of diductor scars are radially and sparsely striated. Coarse pustules are distributed postero-lateral to the muscle field. Fine pustules form dense radiating rows on remainder of valve interior except muscle field. Narrow radiating grooves are impressed on valve margin, corresponding to prominent costae on the valve exterior. Concentric rugae are also observed.

Dorsal interior: Cardinal process is bilobed, with longitudinally striated or irregular diductor bases, and posteriorly covered with small subcircular chilidium in conjunct condition. A pair of small socket ridges is located lateral to cardinal process, projecting ventro-laterally. The median part of hinge line is covered with denticles. A pair of low but broad ridges without pustules is located lateral to cardinal process and parallel with hinge line (Plate 5, figs. 4–5). Adductor muscle field is located anterior to the cardinal process, acutely triangular in outline, well impressed posteriorly, but marges into the floor of the valve anteriorly. A narrow and round myophragm divides muscle field. The floor of the muscle field is ornamented by radial rows of fine pustules, or by radial striae. Prominent pustules are distributed postero-lateral to the muscle field and the remainder of the valve interior is covered with fine radial rows of pustules. Concentric rugae occur anterior to the muscle field.

COMPARISON:

So far as the author is aware, following species of *Leptostrophia* are known from China; *Leptostrophia heitaiensis* WANG (YANG and WANG, 1955, p. 149, Pl. 85, figs. 5, 7; WANG, 1956c, pp. 586–587, Pl. VII, F; figs. 1–3), *Leptostrophia* cf. *heitaiensis* WANG (HOU, 1959, p. 123, Pl. I, fig. 4), *Leptostrophia mccarthyi* GRABAU (GRABAU, 1931, pp. 11–16; GRABAU, 1933, Pl. III, figs. 9–18; HOU, 1963a, p. 42, Pl. 12, fig. 2; WANG *et al.* 1964, pp. 195–196, Pl. 27, figs. 15–17), *Leptostrophia nonakai* HAMADA (NOKANA, 1944, pp. 250–251, Pl. 27, fig. 1; HOU, 1959, p. 123, Pl. I, figs. 2, 3; WANG *et al.*, 1964, p. 195, Pl. 28, fig. 5; HAMADA, 1971, pp. 48–52, Pl. 9, figs. 1–6, Pl. 10, figs. 1–4, Pl. 30, fig. 1), *Leptostrophia wonghsiangensis* YOH (WANG *et al.*, 1964, p. 196, Pl. 27, figs. 20–21). However, neither of them has surface ornamentation like the present species.

Species with similar type of ornamentation are as follows; *Leptostrophia clarkei* CHATTERTON, from the Emsian to the Eifelian Murrumbidgee Group, Taemas, N. S. W., Australia (CHATTERTON, 1973, pp. 58–61, Pl. 12, figs. 1–13; Pl. 13, figs. 10–17; Pl. 35, figs. 12, 14), *Leptostrophia inequicostella* JOHNSON, from the Siegenian Rabbit Hill Limestone, Central Nevada, U. S. A. (JOHNSON, 1970, pp. 126–127, Pl. 29, figs. 1–8).

Leptostrophia clarkei has dorsal valve on which costae are only slightly stronger than the lirae. But the species differs from *Leptostrophia japonica* sp. nov. in its more closely packed prominent costae on the ventral valve, a wider angle subtended between ventral muscle bounding ridges, medially grooved arrowhead-shaped ventral process, adductor scars which are more strongly impressed than the diductor scars in the ventral interior, and absence of concentric rugae.

Leptostrophia inequicostella has similar type of surface ornamentation, but careful observation reveals that this species has weaker costae on ventral valve and coarser lirae on dorsal valve than the presently described species. *Leptostrophia inequicostella* also differs from *Leptostrophia japonica* in its small size (about a half size of the latter), the inverted T-shaped ventral process and the adductor scars which are more strongly impressed than diductor scars in the ventral interior.

DIMENSIONS:

sample no.	valve	length	width
JP31035	ventral exterior	21.8	27.8*
JP31036	ventral exterior	26.1	33.2*
JP31042	ventral exterior	29.0	34.5
JP31044	ventral internal mold	20.0	27.8*
JP31045	ventral internal mold	22.4	29.6
JP31040	dorsal external mold	20.0	24.8*
JP31046	dorsal internal mold	19.4	25.2*

Measurements are in mm. *: twiced value from the measurement on a half side of the valve in regard of the plane of symmetry.

Superfamily Davidsoniacea KING, 1850

Family Schuchertellidae WILLIAMS, 1953

Subfamily Schuchertellinae WILLIAMS, 1953

Genus *Schuchertella* GIRTY, 1904

"*Schuchertella*" sp.

Plate 6, figs. 7–11

MATERIAL: 20 specimens are available.

DESCRIPTION:

Ventral exterior: Valve is nearly flat, hemi-circular in outline. Ventral umbo projects posteriorly from the hinge line only about 1/10 of the valve length. The lateral margins of the umbo are straight or slightly incurved, and subtend between them an angle of about 160 to 170 degrees. The cardinal extremities are angular, and the cardinal angle is about right angle. Short lateral margins are straight or gently round, nearly parallel to each other. The anterior margin is round. The ventral interarea is apsacline. The median part of the interarea is occupied by the convex pseudodeltidium, the margins of which enclose posteriorly about 49 to 65 degrees. The interarea and the pseudodeltidium is finely and transversely striated. The surface ornamentation is parvicostellate. The costellae increase in number by insertion. They are numbered about 13 to 19 per 1 cm at 1 cm anterior from the beak. Very fine concentric growth lamellae are observed on both costellae and interspeces, numbered about 3 to 6 in 1 mm length.

Dorsal exterior: Valve lacks umbo, and posterior margin is straight, coinsiding with the hinge line. Other features of outline and surface ornamentation are identical as those on the ventral valve.

Ventral interior: A pair of incipient dental plates which supports teeth is confined posteriorly under the interarea. Muscle scars are not impressed. Interior of the valve is costellate, reflecting the parvicostellate surface ornamentation.

Dorsal interior: Bilobed cardinal process is oriented postero-ventrally in lateral view. The socket ridges bound the cardinal process laterally, and they are a little elongate, and widely divergent. A short median ridge is observed, which is confined to the base of the cardinal process.

DIMENSIONS:

sample no.	valve	length	width
JP31049	ventral external mold	26.9	32.9
JP31050	ventral exterior	31.2	38.6
JP31051	ventral internal mold	33.9	46.7

Measurements are in mm.

Suborder Chonetidina MUIR-WOOD, 1955
Superfamily Chonetacea BRONN, 1862
Chonetacea gen. et sp. indet.
Plate 6, figs. 1–6

MATERIAL: About 20 specimens are available, but many of them are fragmental.

DESCRIPTION:

The shell is concavo-convex, and hemi-circular in outline. Both the length and the width are less than 1 cm. The ratio of the length to the width is about 1. The hinge line is straight. The cardinal angle is about 70 to 120 degrees, but the variation is probably owing to the post-depositional deformation.

Ventral exterior: Spines project from the ventral interarea and 4 pairs are observed in larger shells. The orientation of them is disturbed by the post-depositional deformation. They are longer laterally and shorter medially, and disposed at nearly regular intervals on each side of the hinge line. But the interval between the median-most pair is shorter than others. Surface ornamentation consists of capillae with **U**-shaped cross-section. Capillae increase in number by bifurcation and insertion, and separated from each other by narrow **U**-shaped interspaces. About 14 to 18 capillae are observed in 5 mm width at 5 mm from the beak.

Dorsal exterior: Outline and surface ornamentation are similar to those of ventral valve. Internal structures are unknown.

DIMENSIONS:

sample no.	valve	length	width
JP31056	ventral exterior	8.34	7.70*
JP31059	ventral exterior	4.30	4.80*

Measurements are in mm. *: twiced value from the measurement on a half side of the valve in regard of the plane of symmetry.

Order Pentamerida SCHUCHERT et COOPER, 1931
Suborder Pentameridina SCHUCHERT et COOPER, 1931
Superfamily Pentameracea M'COY, 1844
Family Pentameridae M'COY, 1844
Subfamily Gypidulinae SCHUCHERT et LEVENE, 1929
Gypidulinae gen. et sp. indet.
Plate 7, figs. 1, 2

MATERIAL: Two ventral valve fragments are available.

DESCRIPTION:

The valve is strongly convex. The outline is uncertain because the anterior parts of the samples are broken. Umbo strongly projects posteriorly from the hinge line. The beak is strongly curved and subtends about 70 to 90 degrees. Interarea and delthyrial structures are unknown. Valve contains a pair of prominent costae with sub-triangular cross-section, radiating from the beak and becoming prominent anteriorly, and subtending about 20 to 25 degrees between them. Among the prominent costae and lateral to them are a few weaker costae with sub-triangular cross-section.

COMPARISON:

Although represented by only 2 fragmental shells, this form is characterized in large shell, and a pair of stronger costae along with a few weaker costae between and lateral to them. Taking these characters into consderation, it is suggested that this form differs from the species of *Gypidula* known in south China.

In south China *Gypidula biplicata* (SCHUNUR) (HOU, 1963a, p. 31, Pl. 8, figs. 2–3) and *Gypidula loczyi* GRABAU (GRABAU, 1931, pp. 75–77, text-fig. 4; HOU and XIAN, 1975, pp. 27–28, Pl. 4, figs. 11–14) are known from the Emsian Yukiang Formation (HOU and XIAN, 1975). But both of them are smaller than the presently described form and have rather different types of costae.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31060	ventral exterior	31.5	34.8	14.1
JP31061	ventral exterior	25.4	23.9	12.2

Measurements are all in mm.

Order Rhynchonellida KUHN, 1949
Rhynchonellida gen. et sp. indet. forma a
Plate 7, figs. 5–9

MATERIAL: 11 samples are available.

DESCRIPTION:

Ventral exterior: Ventral valve is strongly convex, non-strophic, with transversely elongate sub-pentagonal outline. The maximum width is located near the mid-length. Umbo is rostrate. The postero-lateral and antero-lateral margins are gently curved, and the anterior margin deflects posteriorly, reflecting the shape of the median sulcus with trapezoidal cross-section. A few plications are observed on the bottom of the sulcus. Each flank has 5 to 7 plications. The plications both on the bottom of the sulcus and on the flanks are acutely **V**-shaped in cross-section and separated from each other by acutely **V**-shaped interspaces. The whole surface is densely striated by fine growth lines.

Dorsal exterior: The valve is gently convex, and sub-pentagonal in outline. The maximum width is located at about anterior 1/3 of the valve length from the beak. The posterior margins are long, widely divergent from each other. The lateral margins are roundly curved. Morphology of the anterior margin is uncertain. The median fold is trapezoidal in cross-section, bearing a few plications on it. Each flank has 4 to 5 plications. The morphology of the plications is identical to those on the ventral valve. Ventral interior and dorsal interior are unknown.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31063	ventral exterior	14.3	14.7	5.2
JP31065	dorsal exterior	9.0	11.1	1.9

Measurements are in mm.

Rhynchonellida gen. et sp. indet. forma b
Plate 7, figs. 3, 4

MATERIAL: 6 specimens are available.

DESCRIPTION:

Ventral exterior: Valve is strongly convex, circular to sub-pentagonal in outline. The valve length is slightly smaller than the width. Shallow median sulcus is with **V**-shaped cross-section and associated on its bottom with a low plication with roundly **V**-shaped cross-section. The sulcus occupies 1/3 to 1/2 of the valve width at the anterior margin of the valve, projecting dorsally as a strong tongue. 5 to 7 plications with roundly **V**-shaped cross-sections occupy each flank, separated by shallow interspaces. Fine and dense concentric growth lines cover the valve surface.

Drosal exterior: Valve is convex, sub-circular in outline. Short interarea is anacline. Median fold is with **M**-shaped cross-section, owing to a shallow groove on its top. 5 to 6 plications similar to those on the ventral valve cover each flank.

Ventral interior: Delthyrial cavity is thickened. Small teeth are supported on weak dental plates. Adductor scars are longitudinally elongate small platforms located on the posterior part of the median ridge, which reflects the sulcus on the exterior. Diductor scars are longitudinally elongate depressions, located antero-lateral to the adductor scars.

Dorsal interior: Small septalium is located under a pair of discrete hinge plates at the postero-median extremity of the valve interior, supported by a weak median ridge. Other features are uncertain.

COMPARISON:

This form is easily distinguished from Rhynchonellida gen. et sp. indet. forma a in ventral sulcus which has invariably one plication on its bottom, and dorsal fold which also has invariably one shallow groove on its top. This form is also distinguished from Rhynchonellida gen. et sp. indet. forma a in more circular outline, more round cross-sections of the plications.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31068	ventral internal mold	10.8	11.2	4.1
JP31067	dorsal internal mold	12.4	13.8*	4.5
JP31122	dorsal external mold	9.8	10.6*	3.4

Measurements are in mm. *: twiced value from the measurement on a half side of the valve in regard of the plane of symmetry.

Order Spiriferida WAAGEN, 1883
Suborder Atrypidina MOORE, 1952
Superfamily Atrypacea GILL, 1871
Family Atrypidae GILL, 1871
Atrypidae gen. et sp. indet. forma a
Plate 7, fig. 10; Plate 8, figs. 1–6

MATERIAL: About 20 specimens are available.

DESCRIPTION:

Ventral exterior: Valve is weakly convex, shield-shaped to nearly circular in outline. The valve length is about 9/10 of the valve width. The small umbo is incurved, without interarea. The median sulcus is present on the antero-median portion of larger shells, occupying anterior 2/5 of the valve length, and median 1/3 of the valve width at the anterior margin of the valve. The median sulcus bends abruptly nearly at right angles dorsally at the anterior margin of the valve.

Costae radiate from the beak and increase in number by bifurcation. About 6 costae are present in 5 mm width at 5 mm from the beak. The costae are interrupted by concentric growth lamellae (imbricate condition; COPPER, 1967). The concentric growth lamellae are distributed with wide intervals near the beak, more frequently around the valve margin.

Dorsal exterior: Valve is strongly convex, nearly hemi-spherical, and circular in outline. The beak and the interarea are obsolescent. The anterior margin of the valve is deflected dorsally. The deflection is gently arched in anterior view. Valve is covered with coarsely imbricate ornamentation as on the ventral valve. Costae are numbered about 7 in 5 mm width at 5 mm from the beak.

Ventral interior: A pair of narrow elongate low ridges rimms the posterior margins of the valve, and is separated from the teeth by a pair of **U**-shaped grooves. The teeth and the grooves are supported on a thick shelly pads, the bases of which are shallowly excavated except the portions immediately under the teeth.

The muscle field is elongate pear-shape in outline, and occupies the posterior 2/3 and the median 1/2 of the valve interior. The adductor muscle field is elongately rhomboidal and occupies median 3/10 of the muscle field, extending anteriorly as far as the anterior end of the muscle field. The postero-lateral margins of the adductor scar are sometimes bounded by a pair of ridges with **U**-shaped cross-section. Narrow median groove is sometimes observed on posterior part of the adductor scar. A pair of diductor scars bounds the adductor scar laterally, and is bounded with weakly elevated lateral margins, and longitudinally striated. The postero-lateral portions of the valve are covered with many small genital markings, which are sometimes observed also on the valve floor anterior to the muscle field.

Dorsal interior: The dorsal valve interior is examined only with 2 specimens; an internal mold JP31072 (Plate 8, figs. 2a–e), and a serial grinding sections of a conjoined shell, JP31077.

Cardinal process which consists of a pair of disjunct small triangular lobes is located at the postero-median extremity of the valve. A pair of the hinge plates, which initiates from the anterior ends of the cardinal process lobes, is located along the postero-lateral margins of the valve, separated from them by sockets with **U**-shaped cross-sections. Each socket is associated with weak middle ridge and crenulated. An inner socket ridge and a crural base are located on the ventral side of each hinge plate. Crural bases are more medially located than inner socket ridges, and separated from the latter by a shallow groove with **U**-shaped cross-section. The crural bases are directed ventro-laterally. Crura and juga are not observed. Anterior to the notothyrial platform, a pair of muscle scars occupies the postero-median portion of the valve, and is divided by the median ridge with **U**-shaped cross-section. Each scar is fan-shaped, ornamented with radial fine ridges. Muscle bounding ridges are absent.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31070	ventral exterior	29.4	28.5	—
JP31071	ventral exterior	21.1	25.2	—
JP31077	ventral exterior	31.9	32.4	—
JP31070	dorsal exterior	29.4	28.5	11.8
JP31077	dorsal exterior	31.9	32.4	12.2

Measurements are in mm.

Atrypidae gen. et sp. indet. forma b
Plate 8, figs. 7–9; Plate 9, figs. 1–4

MATERIAL: 11 samples are available.

DESCRIPTION:

Ventral valve is shield-shaped in outline. The length is nearly equal to the width. The beak projects slightly behind the hinge axis. Surface ornamentation consists of costellae, which are interrupted by widely speced strong concentric growth lamellae. The costellae are numbered about 5 to 8 in 5 mm width at 5 mm from the beak. Sometimes a shelly frill is present, projecting antero-ventrally from a certain concentric growth line, which is located near the valve margin (Plate 8, fig. 8). Costellae sometimes abruptly increase in number mainly by bifurcation and sometimes by insertion just anterior to a certain growth lamella, which is, in the present material, located at about 10 to 12 mm anterior from the beak, and posterior to the one from which a shelly frill grows. This type of costellae are numbered about 11 in 5 mm width. Costellae are separated from each other usually by grooves with **U**-shaped cross-section, but by shallow grooves with **V**-shaped cross-section after the abrupt increase of the costellae. Shelly frill is also ornamented by costellae, which are numbered about 5 to 8 in 5 mm width and separated from each other by narrow grooves with **U**-shaped cross-section.

The outline of the dorsal valve is not well studied. Surface ornamentation is identical to that on the ventral valve. The shelly frill is not observed among the presently examined specimens.

Ventral and dorsal interiors are uncertain. Strong muscle impressions are not observed in either valve interior.

COMPARISON:

This form is clearly distinguished from Atrypidae gen. et sp. indet. forma a, in more gently convex dorsal valve and lack of strongly impressed ventral muscle scars. This form is also distinguished from Atrypidae gen. et sp. indet. forma a in possession of a shelly fringe at least along the ventral margin, and more finely costellate surface ornamentation. An abrupt increase of the costellae anterior to a certain growth line is also characteristic to this form.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31080	ventral external mold	22.5	20.8*	—
JP31083	ventral internal mold	21.7	23.6	4.7

Measurements are in mm. *: twiced value from the measurement on a half side of the valve in regard of the plane of symmetry.

Suborder Spiriferidina WAAGEN, 1883

Superfamily Spiriferacea KING, 1846

Family Eospiriferidae SCHUCHERT et LEVENE, 1929

Subfamily Eospiriferinae SCHUCHERT et LEVENE, 1929

emended BOUCOT, 1962

Genus *Eospirifer* SCHUCHERT, 1913

Eospirifer variplicatus sp. nov.

Plate 9, figs. 5–9; Plate 10, figs. 1–8

HOLOTYPE: JP31089, a ventral valve (Plate 9, fig. 6)

MATERIAL: 40 sepcimens are available.

DIAGNOSIS: Shell is strongly biconvex with very high tongue at the anterior margin of the ventral valve. 1 to 4 plications are present on each flank in the earlier stage of growth, frequently becomming weaker or almost fading out in the later stage. Plications occasionally bifurcate anteriorly. In ventral interior strong dental lamellae extend from the beak anteriorly about 1/3 to 1/2 of the valve length. In larger shells, the umbonal cavity is divided into the larger anterior and the smaller posterior portions by differential thickening of the dental lamellae.

DESCRIPTION:

Ventral exterior: Valve is strongly convex, transversely elliptical in outline. The hinge line is short. Cardinal and lateral margins are gently curved and the antero-median margin is straight or slightly incurved. The maximum width is at a little posterior to mid-length. The ventral umbo prominently projects posteriorly behind the hinge line, bounded by almost straight or a little incurved lateral margins with an apical angle of about 90 to 130 degrees. The interarea is concave and apsacline to orthocline, with open delthyrium. Delthyrial angle is 21 to 38 degrees, varying porbably owing to post-depositional deformation to a certain extent. Sulcus is with shallowly **U**-shaped to roundly trapezoidal cross-section, projecting as a tougue anteriorly. On anterior margin the width of the sulcus attains about 1/3 of the valve width. Posterior portion of each flank bears 1 to 4 obvious round plications which are separated by shallow and round interspaces. Plications frequently become weak or vestigial anteriorly, sometimes bifurcating. Micro-ornamentation consists of fine radial fila, which increase in number anteriorly, mainly by bifurcation. 20 to 30 fila are numbered per 5 mm width, at 1 cm from the beak.

Dorsal exterior: Valve is equally convex as ventral valve, and transversely elliptical in outline. Umbo extends scarcely beyond the hinge line. Interarea is very small, probably apsacline. Fold is shallowly **U**-shaped or roundly trapezoidal in cross-section, bounded at its lateral margins by a pair of narrow **U**-shaped grooves. Surface ornamentation is identical to that on the ventral valve.

Ventral interior: Dental plates are well developed, extending straight anteriorly about 1/3 to 1/2 of the valve length. The angle subtended between them varies from 14 to 37 degrees. In larger specimens secondary lateral thickening of the plates occurs, most porminently just anterior to the posterior extremity of the umbo and, as a result, umbonal cavity waists and forms posterior smaller longtudinally elongate, and anterior larger cavities. A low, but acute median ridge sometimes occupies the posterior cavity. Secondary thickening of the dental plates is associated with that of posterior part of the valve floor.

Dorsal interior: Without secondary thickening in the posterior part of the dorsal valve, valve is strongly deformed and only a little is known about cardinalia. Short crural plates are located on the top of plications, which coinside with the grooves bordering the median fold on the valve exterior. Crural plates leave the floor anteriorly and crura project from the dorsal side of the crural plates (Figure 10). Weak median ridge extends anteriorly about 1/10 to 1/3 of the valve length.

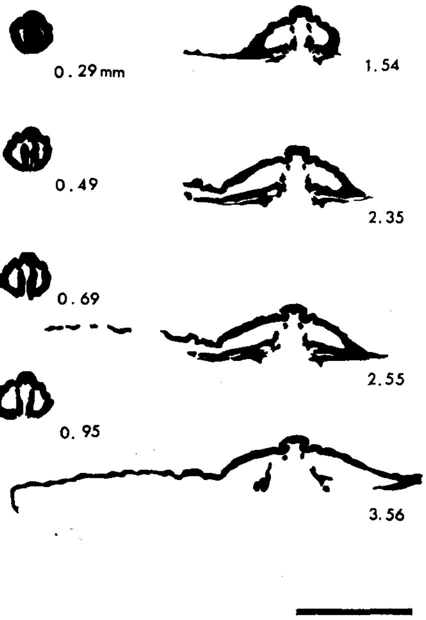

Figure 10. *Eospirifer variplicatus.* Serial grinding sections of a dorsal valve. Each figure represents distance from the beak. Bar represents 10 mm.

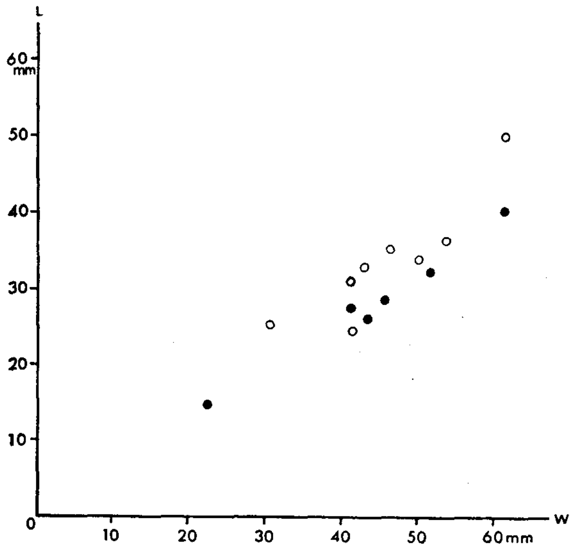

Figure 11. *Eospirifer variplicatus.* Size distribution
L: length, W: width of valve,
open circle: ventral valve
solid circle: dorsal valve

REMARKS and DISCUSSION:

Ontogenic variation is observed on the posterior part of ventral interior. The floor of umbonal cavity is roundly elevated, reflecting the median sulcus on the valve exterior when the valve is small (Plate 10, figs. 2, 4). Then the floor is trilobed into low round ridges (Plate 10, fig. 3). Finally, when the valve becomes greater and the secondary thickening of valve floor as well as that of the dental plates occurs, each lobe increases its height and has roundly U-shaped cross-section. Lateral lobes become wider and extend more anteriorly than the median lobe, and at the same time a low acute median ridge develops in the posterior part of the umbonal cavity as mentioned above.

BOUČOT (1962) reviewed the subfamily Eospiriferinae. According to him, the subfamily consists of 6 genera, *Eospirifer*, *Macropleura*, *Striispirifer*, *Havlicekia*, *Nikiforovaena*, and *Janius*, which are distinguished from each other mainlyon the basis of plication type.

Among well preserved 19 specimens of the presently described species, 7 have plications, many of which are clearly observed throughout ontogeny. Remainders have plications, many of which are clearly observed on the posterior part of the flanks, but almost fading away anteriorly. In addition, occasionally, bifurcations are observed on some plications of shells with both type of plications. The first type of plication is characteristic to *Striispirifer*, the second type of *Havlicekia*, the third type reminds of plication type of *Janius*, although in *Janius* bifurcation is invariably observed. These plication types in the present specimens occur not as a discrete but as a continuous variation. Thus it is difficult to assign presently described species into the classification by BOUCOT (1962).

Several species included in the subfamily show wide variations in plication, although the mode of variation is different from the presently described species. SAVAGE (1974) pointed out that *Eospirifer parahentius* GILL from the Lower Devonian Maradana Shale, New South Wales, Australia, which shows plication type intermediate between those of *Eospirifer* and *Macropleura*. Specimens described by KULKOV (1967, pp. 111–113, Pl. XIX, figs. 1–6) from the Silurian of Altai Mountains as *Eospirifer radiatus* (SOWERBY) and its variation *Eospirifer radiatus* var. *plana* have three types of plications, i.e., *Eospirifer* type (1967, Pl. XIX, figs. 1, 2, 5,), *Striispirifer* type (1967, Pl. XIX, fig. 3), and *Havlicekia* type (1967, Pl. XIX, fig. 4), if the specimens really represent a intra-specific variation.

Taking above stated facts into consideration, classification of the subfamily Eospiriferinae by BOUCOT (1962) should be modified in near future to assign above mentioned species to a reasonable suite. The present author tentatively assigns the presently described species to the genus *Eospirifer*.

COMPARISON:

As stated above, presently described species has a peculiar type of plication, so it is difficult to find similar species. *Eospirifer parahentius* GILL (SAVAGE, 1974, pp. 34–35, Pl. 9, figs. 1–20) is the most similar species to *Eospirifer variplicatus* sp. nov. Outline and ventral internal structures of both species are quite similar. But *Eospirifer parahentius* is smaller in size than *Eospirifer variplicatus* (According to measurements in SAVAGE, 1974, the largest shell has a length of 17.0 mm and a width of 19.7 mm. Compare these figures with the dimensions on *Eospirifer variplicatus* given below.). *Eospirifer parahentius* is also distinguished in lacking plications which bifurcate anteriorly.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31089	ventral exterior	24.5	41.2*	6.8
JP31090	ventral exterior	32.9	42.9	15.0
JP31091	ventral internal mold	25.3	30.8*	4.5
JP31098	ventral exterior	34.0	50.0*	9.0
JP31099	ventral internal mold	35.1	46.2*	4.9
JP31100	ventral exterior	36.5	53.9	5.3
JP31085	dorsal exterior	14.5	22.7	2.5
JP31086	dorsal exterior	28.4	45.8*	7.2
JP31088	dorsal exterior	32.2	51.6*	5.0
JP31101	dorsal internal mold	26.0	43.3	1.8

Measurements are in mm. *: twiced value from the measurement on a half side of the valve in regard of the plane of symmetry.

Superfamily Spiriferacea KING, 1846

Family Delthyrididae WAAGEN, 1883

Subfamily Acrospiriferinae TERMIER et TERMIER, 1949

Genus *Howellella* KOZLOWSKI, 1946

Howellella sp. a

Plate 11, figs. 1–8

MATERIAL: About 15 specimens are available.

DESCRIPTION:

Ventral exterior: Valve is gently but more strongly convex than dorsal valve, and transversely elliptical to sub-heptagonal in outline. The valve length is about 3/5 of the maximum width. The umbo projects posteriorly from the hinge line about 3/10 of the valve length, and is bounded by slightly incurved lateral margins. The apical angle is about 130 degrees. The cardinal extremities are obtusely angular; the postero-lateral margins are short, straight, and slightly divergent anteriorly; the antero-lateral margins are gently rounded; the anterior margin is straight or slightly incurved, forming the anterior end of the sulcus. The median sulcus is shallowly **U**-shaped in cross-section and its margins subtend an angle of about 18 degrees. The width of the sulcus attains about 1/3 of the valve width at the anterior margin. About 5 to 9 plications are present on each flank. They are roundly **U**-shaped in cross-section and separated from each other by roundly **V**-shaped interspaces. The plications gradually decrease in width from the median part to the lateral margins. Interarea is apsacline, weakly curved, high. The delthyrium is broadly open, with delthyrial angle of about 80 degrees, and laterally bounded by a pair of shallow **U**-shaped grooves which increase in width from apical region to the hinge line. Micro-ornamentation consists of weak lamellae and capillae on them.

Dorsal exterior: Valve is gently convex, and transversely elongate elliptical to semi heptagonal in outline, with the valve length about 7/10 of the maximum width. The umbo is not developed. The cardinal extremities are obtusely angular. The postero-lateral margins are short, straight and sub-parallel or slightly divergent anteriorly. The antero-lateral margins are gently rounded and the anterior margin is straight to slightly incurved posteriorly. The median fold is low trapezoidal in cross-section with wide flat roof and gently rounded lateral slopes. The lateral margins of the fold is bounded by a pair of shallow **U**-shaped grooves. The angle subtended between the lateral margins of the fold varies from 18 to 26 degrees with an average of about 19 degrees. The width of the fold at the anterior margin is about 1/3 of the width of the valve. About 5 to 10 plications are observed on each flank with round **U**-shaped cross-section and separated from each other by shallow roundly **V**-shaped interspaces. Plications gradually decrease in width from the median part to the lateral margins. Micro-ornamentation is identical to that on the ventral valve.

Ventral interior: Dental plates occupy posterior 1/6 of the valve length and subtend an angle of about 27 degrees. A weak and narrow median ridge extends from the beak anteriorly about 1/2 of the valve length (Figure 12)

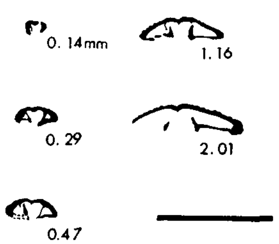

Figure 12. *Howellella* sp. a. Serial grinding sections of a ventral valve. Each figure represents distance from beak. Bar represents 10 mm.

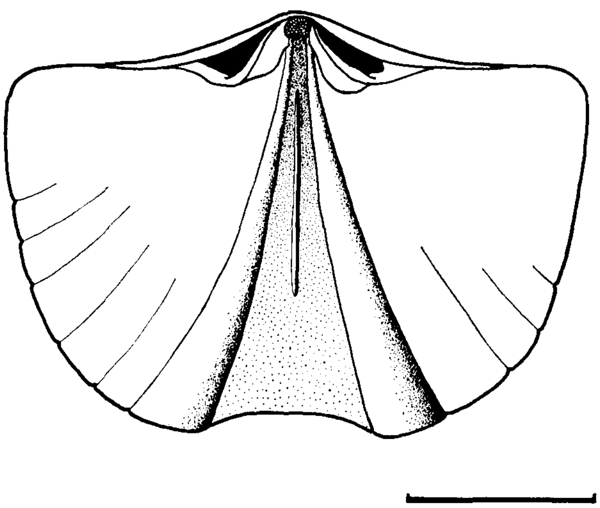

Figure 13. *Howellella* sp. a. Reconstruction of dorsal valve interior. Bar represents 5 mm.

Dorsal interior: The cardinal process shaft elevates gently from the valve floor posteriorly, triangular in lateral view (Figure 13). The myophore is granulated and the shaft is longitudinally striated near the myophore. A pair of the sockets forms narrow slits, bounded with a pair of the thin outer socket ridges and a pair of the thicker inner socket ridges, and located along the posterior margins of the valve. A pair of short crural plates is triangular in lateral view, and inclined to the mid-line. The posterior parts of the crural plates bound the cardinal process and fuse to the valve floor, but anteriorly leave the valve floor gradually.

REMARKS:

In one specimen which shows dorsal interior, a pair of the rod-like crural bases is observed. They initiate beneath the posterior parts of the hinge plates and are slightly divergent anteriorly. This specimen lacks crural plates and it prevents observation of relation between crura and crural plates.

DIMENSIONS:

sample no.	valve	length	width
JP31103	ventral exterior	8.4	14.1
JP31106	ventral exterior	4.8	7.6
JP31109	dorsal exterior	11.6	17.8

Measurements are in mm.

Howellella sp. b
Plate 11, figs. 9–16

MATERIAL: 9 specimens are available.

DESCRIPTION:

Ventral exterior: Ventral exterior is represented by only one fragmental specimen (Plate 11, fig. 12). The valve is convex, and sub-pentagonal in outline. The length is about 3/5 of the width. Umbo projects posteriorly from the hinge line. Its lateral margins are slightly incurved, and subtend an angle of about 170 degrees. Cardinal extremities are round; lateral margins are gently curved and convergent anteriorly; and anterior margin is nearly straight. Median sulcus is shallowly **V**-shaped in cross-section. The margins of the sulcus are bounded by strong plications with **U**-shaped cross-section. The plications subtend an angle of about 30 degrees. Each flank is ornamented with a few plications. They are roundly **U**-shaped in cross-section and separated from each other by shallow **V**-shaped interspaces. Surface of the valve is covered with closely and regularly spaced concentric growth lamellae, which are numbered about 5 per 1 mm length. Fine, short, blunt spines are projecting from the anterior margin of each lamella.

Dorsal exterior: The valve is gently convex, and transversely elongate subelliptical in outline. The length is about 7/10 of the width. Umbo projects posteriorly only slightly behind the hinge line. The lateral margins of the umbo are almost straight, subtend between them an angle of about 155 to 170 degrees. Cardinal extremities are round. Lateral margins are gently cruved. Anterior margin is nearly straight. Median fold is gently **U**-shaped in cross-section, separated from the flanks by narrow **U**-shaped grooves, which subtend between them an angle of 27 to 37 degrees. Each flank contains 1 to 3 plications with gently **U**-shaped cross-sections which are separated from each other by shallow interspaces. The valve surface is covered with the same type of ornamentation as observed on the ventral valve.

Ventral interior: Only one small fragment shows a pair of small dental plates on the ventral interior. Other features are unknown.

Dorsal interior: The cardinal process has a shaft with rectangular cross-section. The shape of the miophore is unknown. The sockets are narrow grooves with **U**-shaped cross-section, parallel to the posterior margins of the valve, and bounded by well developed inner socket ridges. The narrow median ridge initiates from the posterior part of the valve and extends anteriorly about 1/2 of the valve length.

COMPARISON:

The present form is easily distinguished from *Howellella* sp. a in its strong concentric growth lamellae and prominent spines on the growth lamella. This form is also distinguished from the former by its fewer plications on each flank.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31113	ventral exterior	8.8	15.8*	2.8
JP31111	dorsal external mold	8.4	11.2*	1.5
JP31112	dorsal exterior	6.1	8.6	0.7
JP31114	dorsal internal mold	8.4	12.6*	1.8
JP31116	ventral exterior	8.8	13.6*	1.6

Measurements are in mm. *: twiced value from the measurement on a half side of the valve in regard of the plane of symmetry.

Superfamily Suessiacea WAAGEN, 1883

Suessiacea gen. et sp. indet.

Plate 11, figs. 17–19

MATERIAL: 13 specimens are available.

DESCRIPTION:

Ventral exterior: Valve is small, and pyramidal. The outline is triangular. The interarea is high and nearly catacline. The sulcus is narrow, bounded laterally by a pair of strong plications. Another strong plication is observed on each flank besides one which bounds the sulcus. Mirco-ornamentation is lacking.

Dorsal exterior: Valve is gently convex, and sub-elliptical in outline. The median fold is narrow. 1 to 2 plications are observed on each flank. Micro-ornamentation is lacking.

Ventral interior: Ventral internal molds suggest that the present form has a complex delthyrial structure but the ill-preserved nature of the material prevents further investigations.

Dorsal interior: unknown.

DIMENSIONS:

sample no.	valve	length	width	thickness
JP31119	ventral internal mold	2.2	4.6	3.4
JP31121	dorsal exterior	2.8	4.5	—

Measurements are in mm.

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Explanations of Plates

All the specimens illustrated in following plates are deposited in the Department of Geology and Mineralogy, Kyoto University. Figures in parentheses are registration numbers of the department.

Photo: mainly by T. OHNO, partly by Y. OKAZAKI.

Plate 1

Figs. 1–7. *Isorthis (Isorthis) fukujiensis* sp. nov.

1a, b, c, d, e: lateral, posterior, ventral, dorsal and anterior views of a conjoined shell, ×1.5 (JP31005). A part of ventral valve and entire dorsal valve are exfoliated.

2a, b, c, d, e: lateral, posterior, ventral, dorsal and anterior views of a conjoined shell, ×1.5 (JP31006). Holotype.

3: dorsal valve of a small specimen, ×3 (JP31008). See also Figure 7 in Systematic Descriptions.

4: ventral valve internal mold of a small specimen, ×3 (JP31009).

5: ventral valve internal mold of a small specimen, ×2 (JP31010).

6: ventral valve internal mold of a small specimen, ×3 (JP31011).

7: ventral valve, ×1 (JP31007).

Figs. 8, 9. *Crania* sp.

8a, b, c: dorsal and lateral views of dorsal valve internal mold, and its silicon rubber impression, ×2 (JP31001).

9a, b: internal mold and valve interior of dorsal valve, ×2, (JP31002).

Plate 2

Figs. 1–3, 5–9, 11–14. *Isorthis (Isorthis) fukujiensis* sp. nov.

1: dorsal valve interior, ×1.5 (JP31024).

2a, b: dorsal valve internal mold, ×1, and its silicon rubber impression, ×1.1 (JP31026).

3: ventral valve internal mold, ×1 (JP31012).

5a, b, c, d: lateral, ventral and posterior views of ventral valve internal mold, ×1, and its silicon rubber impression, ×1.3 (JP31013).

6a, b: ventral and posterior views of ventral valve internal mold, ×1 (JP31014).

7a, b: ventral valve internal mold, ×1, and its silicon rubber impression, ×1.3 (JP31015).

8: dorsal valve internal mold of small specimen, ×3 (JP31021).

9: dorsal valve internal mold, ×1 (JP31023). OKAZAKI coll.

11: dorsal valve internal mold of small specimen, ×1.5 (JP31020).

12: dorsal valve internal mold of small specimen, ×3 (JP31019).

13: dorsal valve internal mold of small specimen, ×1.5 (JP31022).

14: anterior view of interior of conjoined shell, ×2.6 (JP31025).

Figs. 4, 10. *Crania* sp.

4: dorsal view of a dorsal valve, ×2 (JP31003).

10a, b: ventral valve internal mold and its silicon rubber impression, ×2 (JP31004).

Plate 3

Fig. 1. *"Leptaena"* sp.

1a, b, c, d: lateral (b), ventral (c) and anterior (d) views of ventral valve internal mold and its silicon rubber impression (a), ×1 (JP31028).

Figs. 2–6. *Cymostrophia* sp.

2a, b: posterior and ventral views of ventral valve, ×1 (JP31029).

3a, b, c: posterior, ventral and lateral views of ventral valve, ×1 (JP31030).

4a, b, c, d, e: lateral (a), ventral (c), posterior (d) and anterior (e) views of ventral valve internal mold and its silicon rubber impression (b), ×1 (JP31032). See also Plate 4, fig. 2.

5a, b, c, d, e: posterior, lateral, ventral and anterior views of ventral valve internal mold and its silicon rubber impression, ×1 (JP31033). See also Pl. 4, fig. 3.

6a, b: anterior and ventral views of dorsal valve external mold, ×1 (JP31031).

Plate 4

Figs. 1–3. *Cymostrophia* sp.

1a, b: internal mold of dorsal valve and its silicon rubber impression, ×1 (JP31034).

2: silicon rubber impression of posterior part of ventral valve internal mold, ×2 (JP31032). Impression from the same sample figured in Plate 3, fig. 4.

3: silicon rubber impression of posterior part of ventral valve internal mold, ×2 (JP31033). Impression from the same sample figured in Plate 3, fig. 5.

Figs. 4–10. *Leptostrophia japonica* sp. nov.

4a, b: dorsal valve external mold (b), and its silicon rubber impression (a), ×1.5 (JP31040).

5: dorsal valve, ×1.5 (JP31041).

6: ventral valve, ×1.5 (JP31035). Holotype.

7: ventral valve, ×1.5 (JP31036).

8: ventral valve, ×1.5 (JP31037). A part of valve is exfoliated.

9: ventral valve, ×1.5 (JP31038). A part of valve is exfoliated.

10: ventral valve shell exterior, ×1.5 (JP31039).

Plate 5

Figs. 1–5. *Leptostrophia japonica* sp. nov.

1a, b: ventral valve internal mold and its silicon rubber impression, ×1.5 (JP31043).

2a, b: ventral valve internal mold and its silicon rubber impression, ×1.5 (JP31044).

3a, b: ventral valve internal mold and its silicon rubber impression, ×1.5 (JP31045).

4a, b, c: dorsal valve internal mold (c), its silicon rubber impression in ventral view (b), ×1.5, in posterior oblique view (a), ×2 (JP31046).

5a, b, c: dorsal valve internal mold fragment and its silicon rubber impression in ventral and anterior views, ×5 (JP31047).

Plate 6

Figs. 1–6. Chonetacea gen. et sp. indet.
1: ventral valve external mold, ×5 (JP31053).
2: ventral valve external mold, ×5 (JP31054).
3: ventral valve, ×5 (JP31055).
4: ventral valve, ×3 (JP31056).
5: dorsal valve internal mold fragment, ×5 (JP31057).
6: ventral valve, ×5 (JP31058). A part of valve is exfoliated.
Figs. 7–11. "*Schuchertella*" sp.
7: ventral valve, ×1 (JP31048).
8a, b: ventral valve internal mold and its rubber impression, ×1 (JP31051).
9a, b: dorsal valve internal mold and its silicon rubber impression, ×1 (JP31052).
10a, b: ventral valve external mold (b), and its silicon rubber impression, ×1.5 (JP31049).
11a, b, c: lateral, posterior, and dorsal views of conjoined shell, ×1.5 (JP31050). OKAZAKI coll.

Plate 7

Figs. 1–2. Gypidulinae gen. et sp. indet.
1a, b, c: ventral, dorsal and lateral views of ventral valve, ×1 (JP31060).
2a, b, c: lateral, ventral and dorsal views of ventral valve, ×1 (JP31061).
Figs. 3–4. Rhynchonellida gen. et sp. indet. forma b
3: dorsal valve internal mold, ×2 (JP31067).
4: ventral valve internal mold, ×2 (JP31068).
Figs. 5–9. Rhynchonellida gen. et sp. indet. forma a
5: ventral view of ventral valve, ×1.5 (JP31062).
6a, b, c, d: posterior, anterior, lateral and ventral views of ventral valve, ×1.5 (JP31063).
7a, b: dorsal and ventral views of deformed conjoined shell, ×1.5 (JP31064).
8a, b, c: posterior, lateral and dorsal views of dorsal valve, ×1.5 (JP31065).
9: ventral view of deformed conjoined shell, ×1.5 (JP31070).
Fig. 10. Atrypidae gen. et sp. indet. forma a
10a, b, c, d, e: anterior, posterior, dorsal, lateral and ventral views of conjoined shell, ×1.2 (JP31070).

Plate 8

Figs. 1–6. Atrypidae gen. et sp. indet. forma a
1: ventral valve, ×1.5 (JP31071).
2a, b, c, d, e: dorsal, lateral, posterior and anterior views of dorsal valve internal mold, and its silicon rubber impression, ×1.5 (JP31072).
3: ventral valve internal mold, ×1.5 (JP31073).
4: ventral valve internal mold, ×1.5 (JP31074). Surface is worn to some extent.
5: ventral valve internal mold, ×1.5 (JP31075).
6a, b: ventral valve internal mold, and its silicon rubber impression, ×1.5 (JP31076).

Figs. 7–9. Atrypidae gen. et sp. indet. forma b

7: ventral valve, × 1.5 (JP31078).

8: ventral valve, × 1.5 (JP31079).

9: ventral valve external mold, × 1.5 (JP31080).

Plate 9

Figs. 1–4. Atrypidae gen. et sp. indet. forma b

1: dorsal valve internal mold, × 1.5 (JP31081).

2: ventral valve internal mold, × 1.5 (JP31083).

3: dorsal valve internal mold, × 1.5 (JP31082).

4: ventral valve internal mold fragment, × 1.5 (JP31084).

Figs. 5–9. *Eospirifer variplicatus* sp. nov.

5: dorsal valve, × 1.5 (JP31085).

6a, b, c, d: lateral, ventral, posterior and anterior views of ventral valve, × 1 (JP31089). Holotype.

7a, b, c, d: posterior, anterior, dorsal and lateral views of dorsal valve, × 1 (JP31086).

8: dorsal valve, × 1 (JP31087).

9a, b, c: dorsal, lateral and ventral views of ventral valve, × 1 (JP31090).

Plate 10

Figs. 1–8. *Eospirifer variplicatus* sp. nov.

1: ventral valve, × 1 (JP31088).

2: ventral valve internal mold, × 1.5 (JP31091).

3a, b: internal mold of fragment of ventral valve, showing posterior portion of valve, and its silicon rubber impression, × 1.5 (JP31092).

4a, b: internal mold of fragment of ventral valve showing posterior portion of valve, and its silicon rubber impression, × 1.5 (JP31093).

5a, b: internal mold of fragment of ventral valve, showing posterior portion of valve (b), and its silicon rubber impression (a), × 1.5 (JP31094).

6a, b: internal mold of fragment of ventral valve, showing posterior portion of valve (b), and its silicon rubber impression (a), × 1.5 (JP31095).

7a, b, c: posterior and ventral views of ventral valve internal mold and its rubber impression, × 1 (JP31096).

8a, b: posterior and dorsal views of dorsal valve internal mold, × 1 (JP31097).

Plate 11

Figs. 1–8. *Howellella* sp. a

1a, b, c: posterior (b) and dorsal (c) views of dorsal valve internal mold, × 2, and its rubber impression, × 2.7 (JP31102).

2a, b: posterior and ventral views of ventral valve, × 2 (JP31103).

3: dorsal valve internal mold, × 2 (JP31104).

4: ventral valve internal mold, × 2 (JP31105).

5: ventral valve, × 2 (JP31106).

6: dorsal valve, ×2 (JP31107).

7: ventral valve internal mold, ×2 (JP31108).

8: dorsal valve, ×2 (JP31109).

Figs. 9–16. *Howellella* sp. b

9: dorsal valve internal mold, ×2 (JP31110).

10a, b, c: dorsal valve external mold (b), its silicon rubber impression (a), ×2, and enlargement of part of rubber impression (c), ×14 (JP31111).

11: dorsal valve, ×2 (JP31112).

12: ventral valve, ×2 (JP31113).

13: dorsal valve internal mold, ×2 (JP31114).

14: dorsal valve internal mold, ×2 (JP31115).

15: dorsal valve internal mold, ×2 (JP31116).

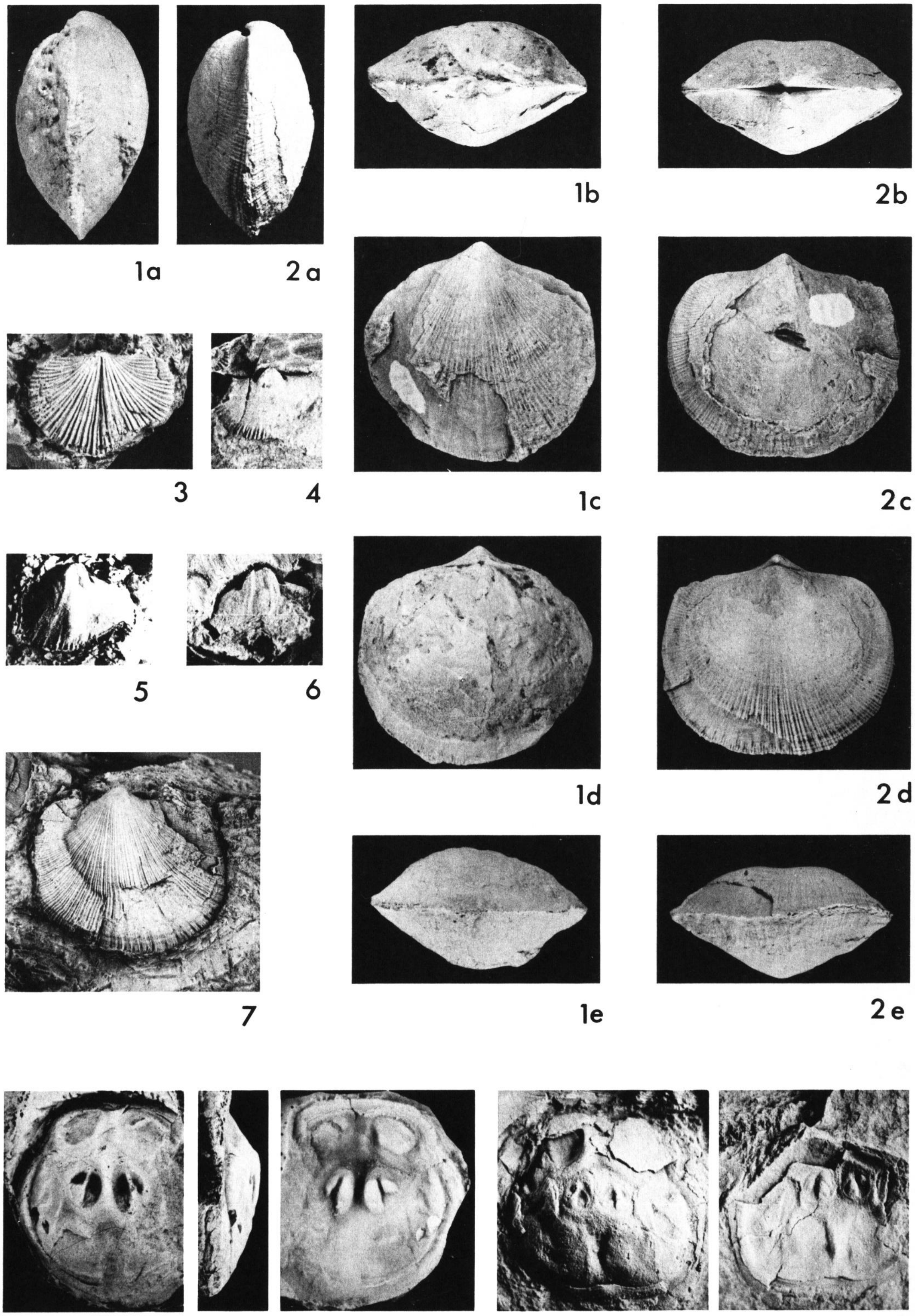
16: dorsal valve shell interior, ×5 (JP31117).

Figs. 17–19. Suessiacea gen. et sp. indet.

17a, b, c: external and internal molds of ventral valve, and silicon rubber impression of external mold, ×5 (JP31118).

18a, b: anterior and posterior views of steinkern, ×5 (JP31119).

19: fragment of internal mold of ventral valve, ×5 (JP31120).



1a 2a 1b 2b 3 4 1c 2c 5 6 1d 2d 7 1e 2e 8a 8b 8c 9a 9b

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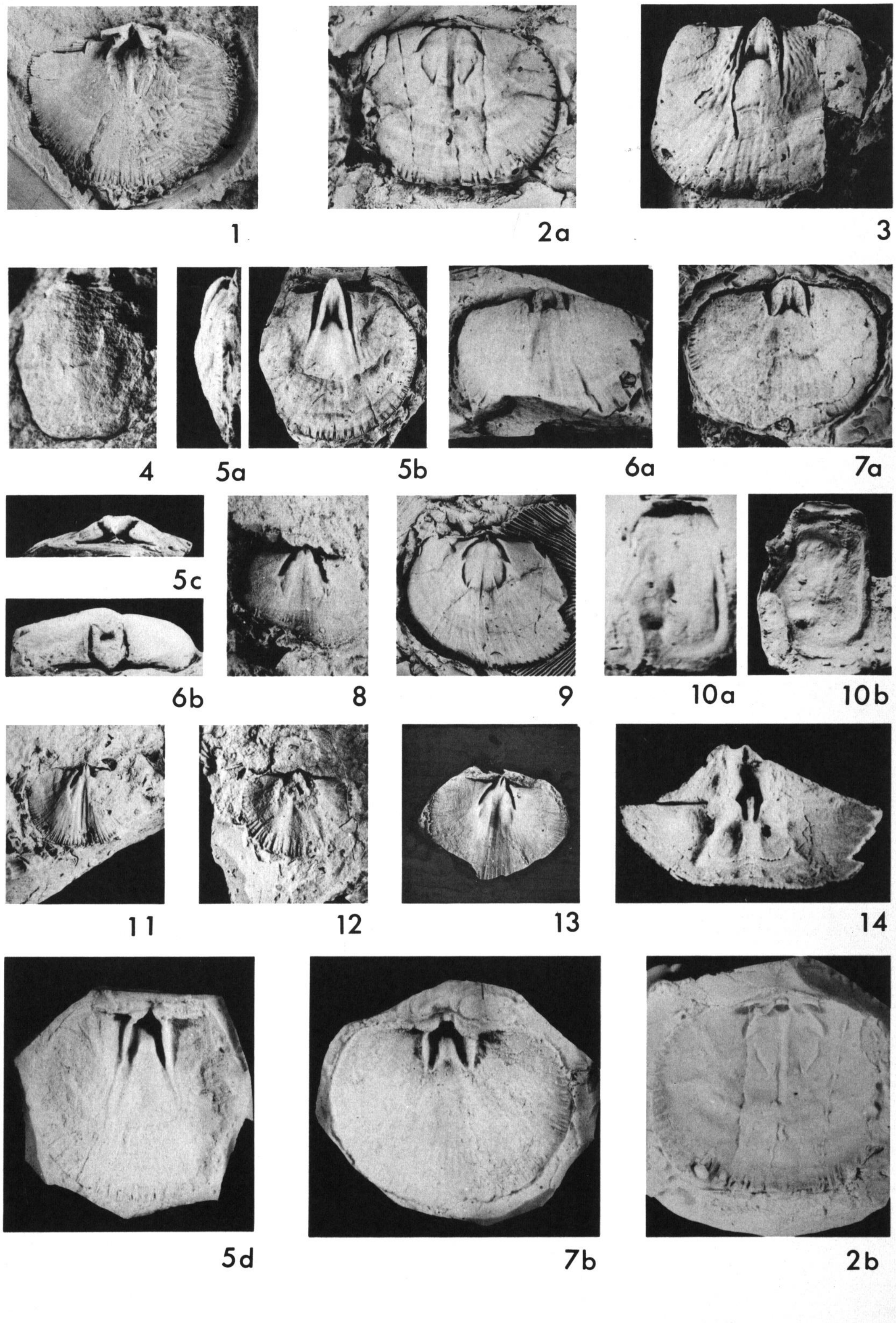

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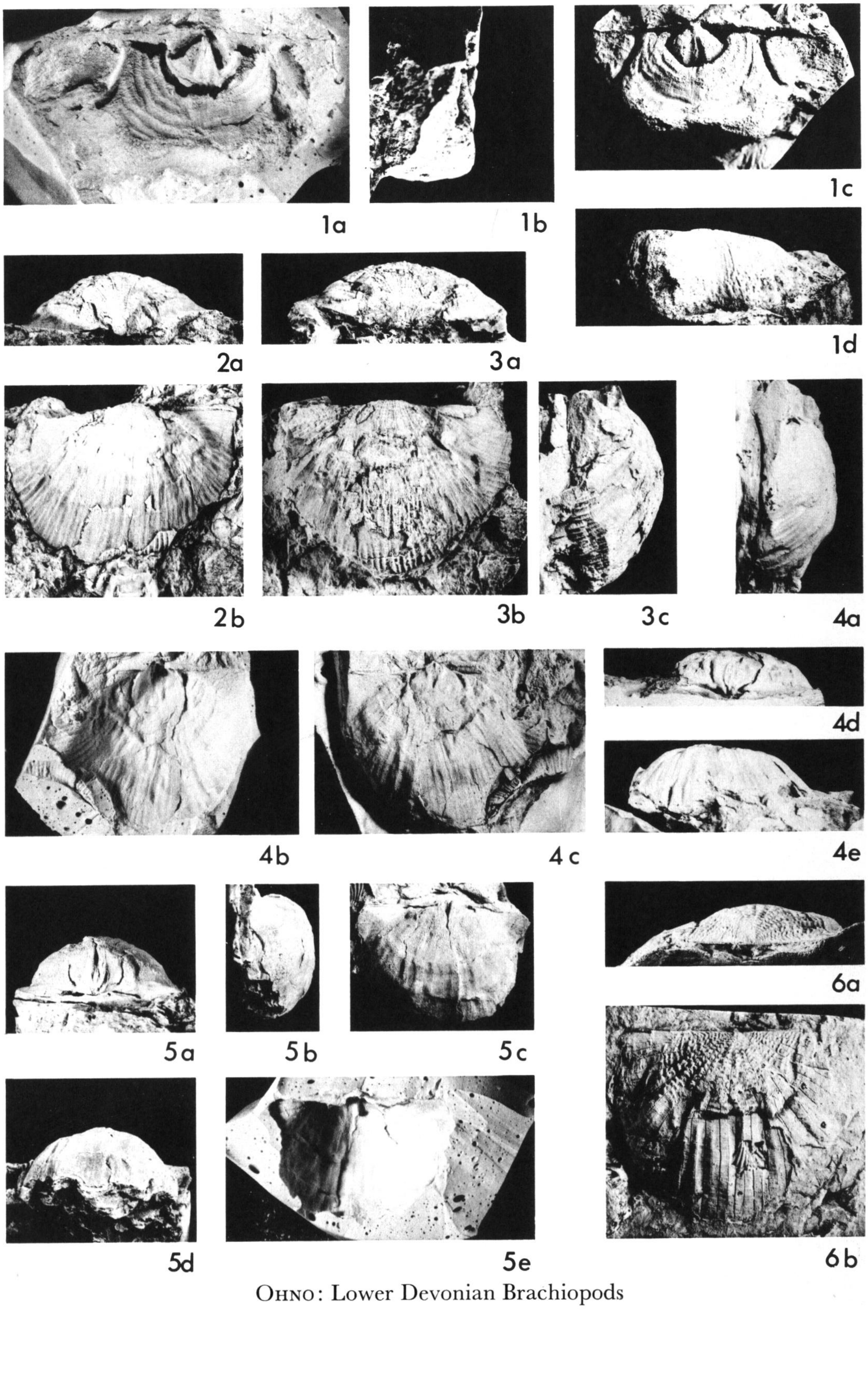

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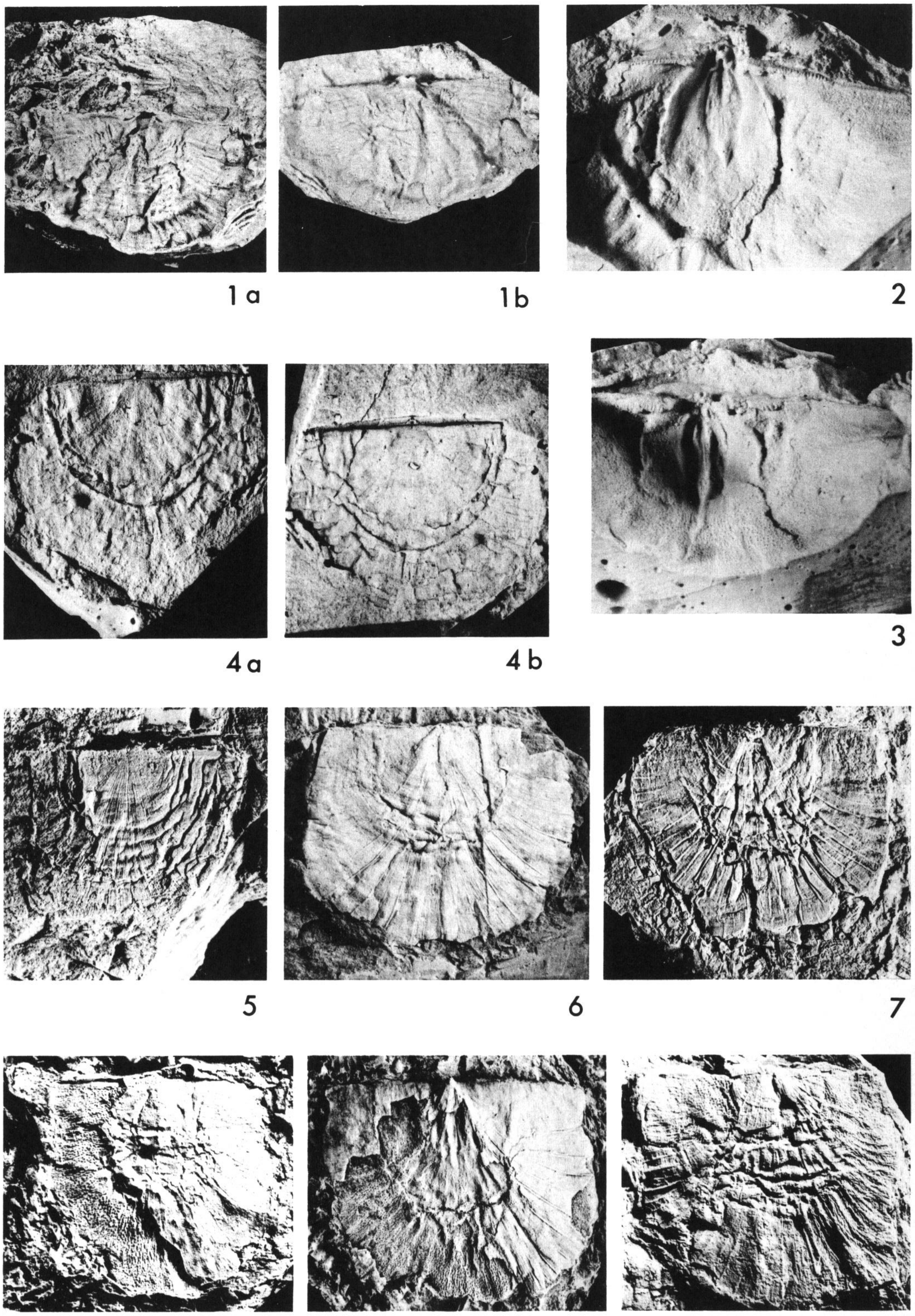

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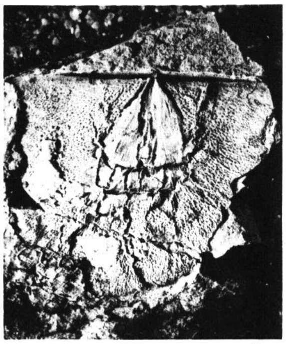
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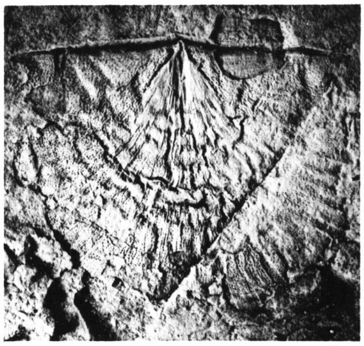
2a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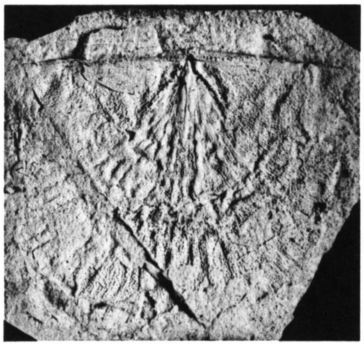
1b


2b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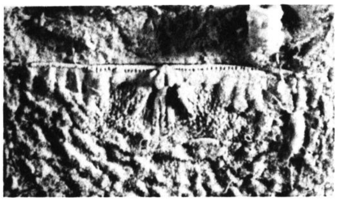
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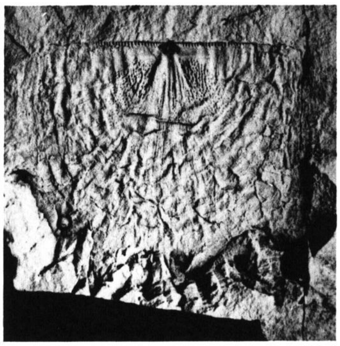
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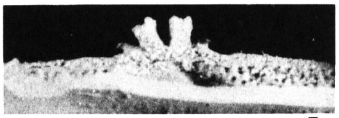
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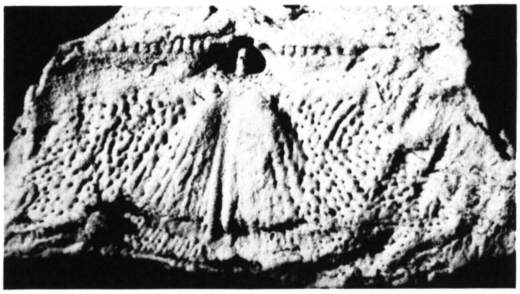
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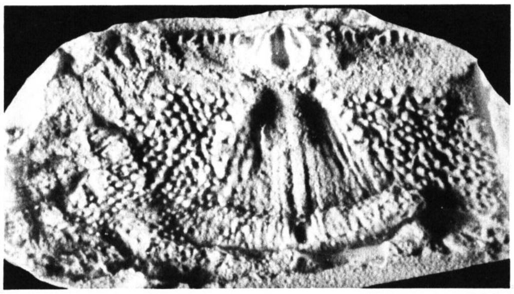
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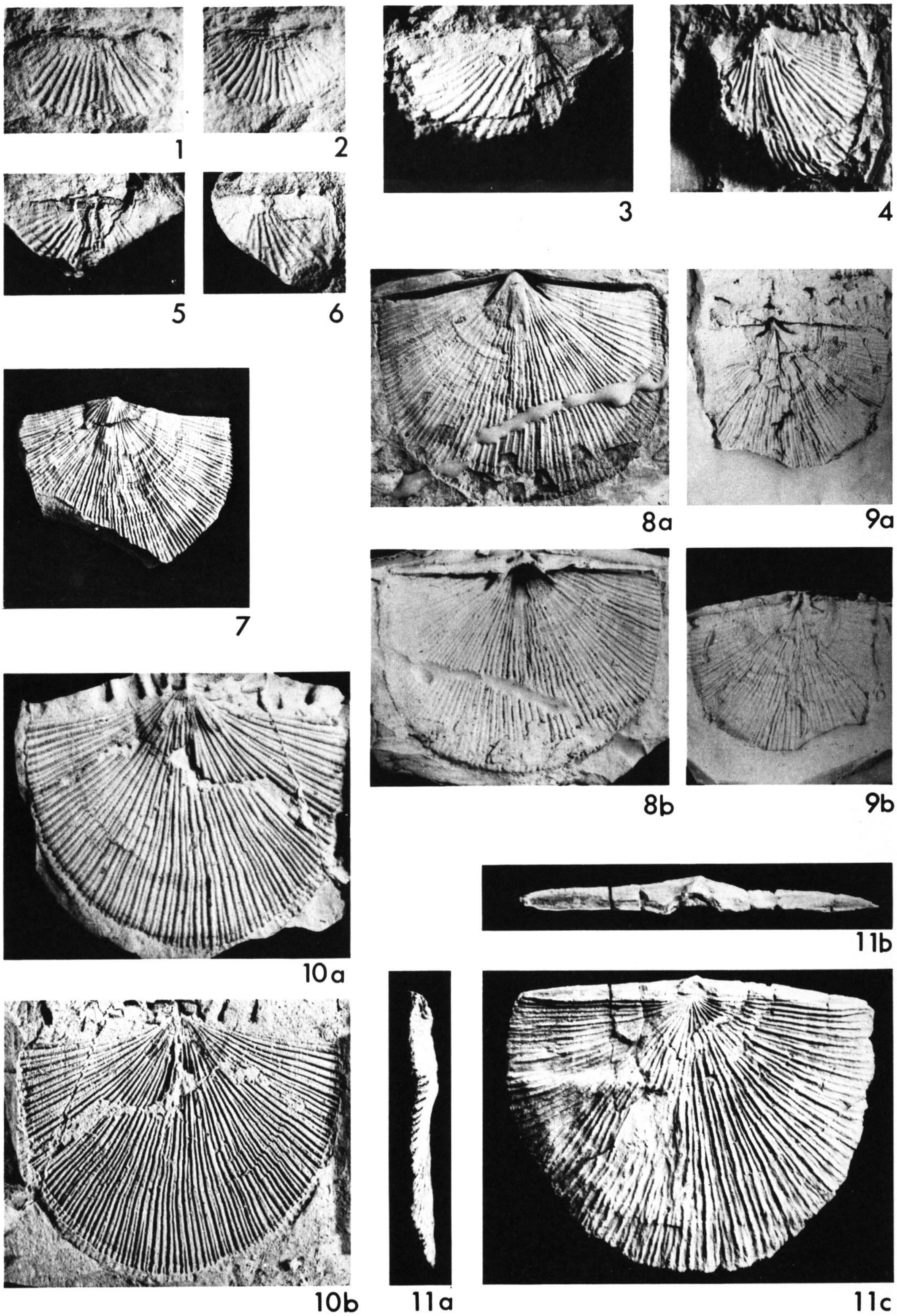

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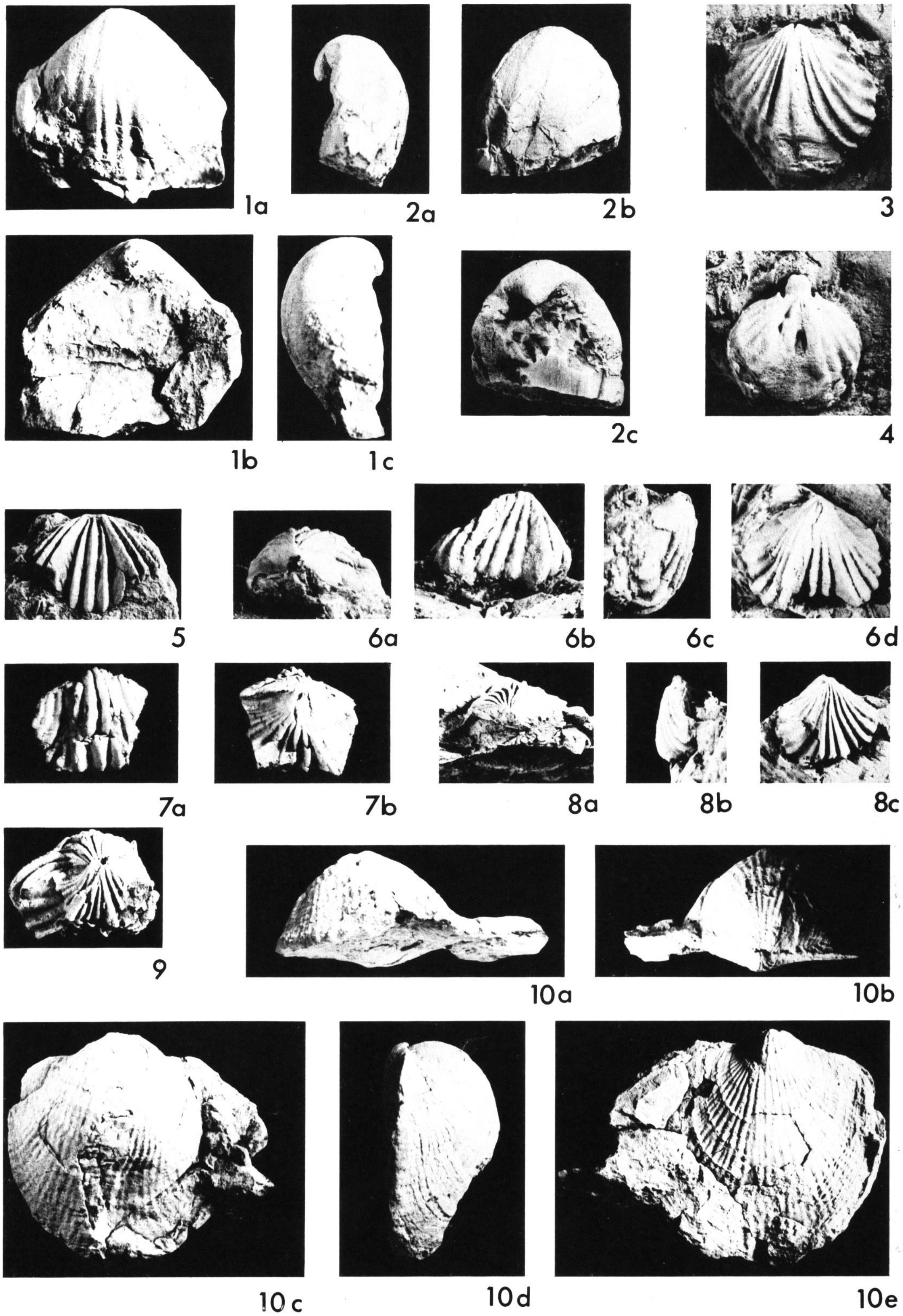

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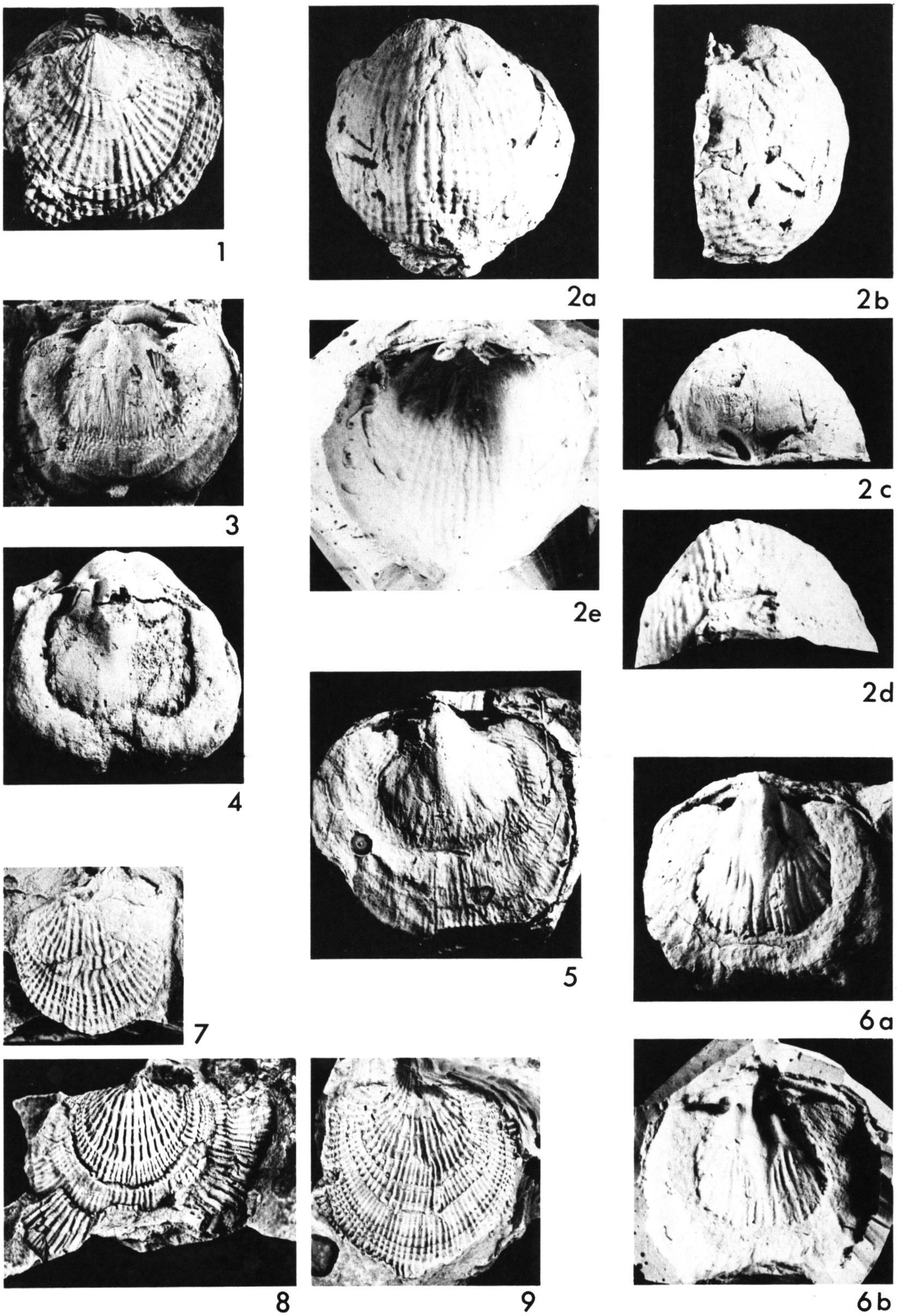

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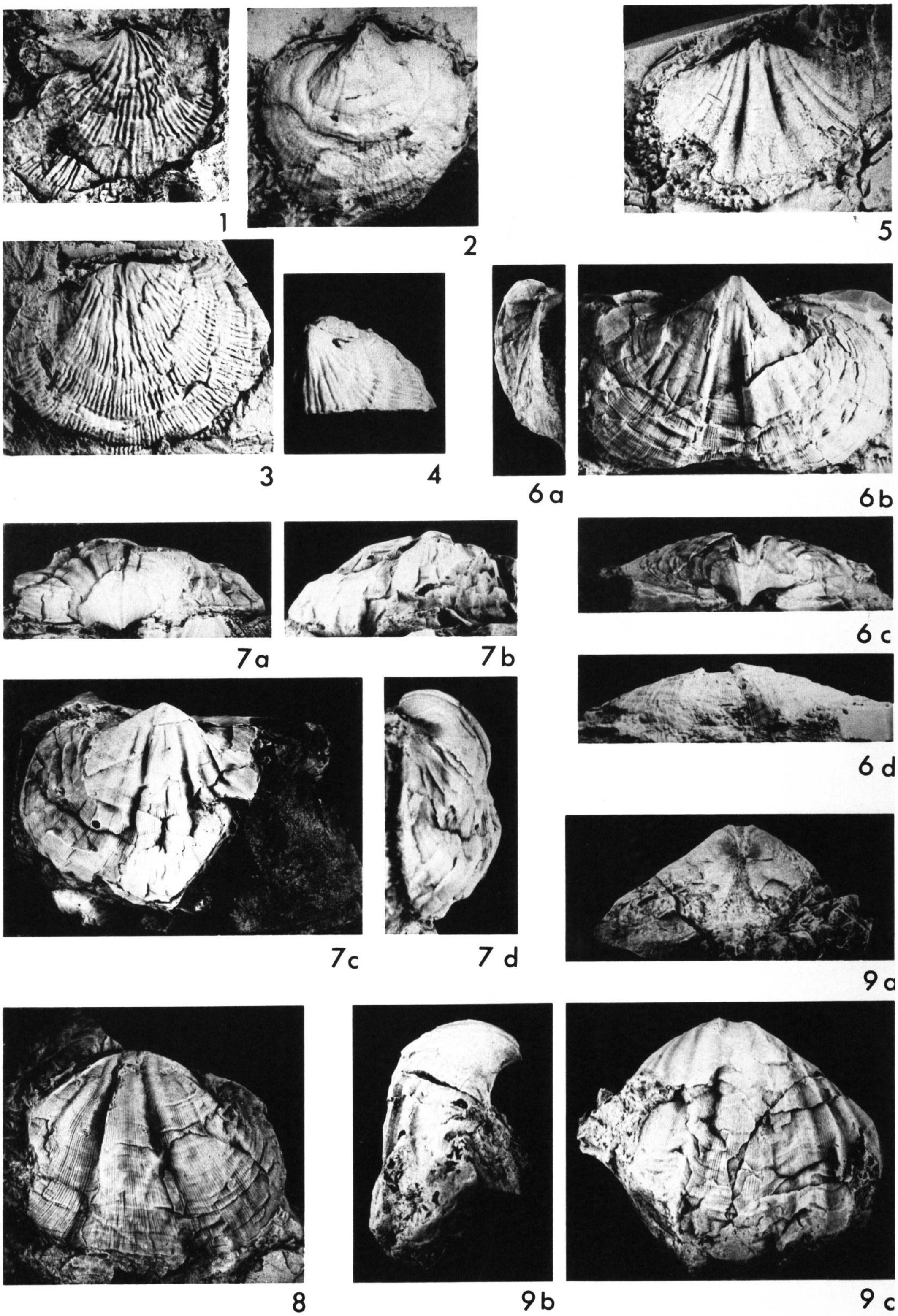

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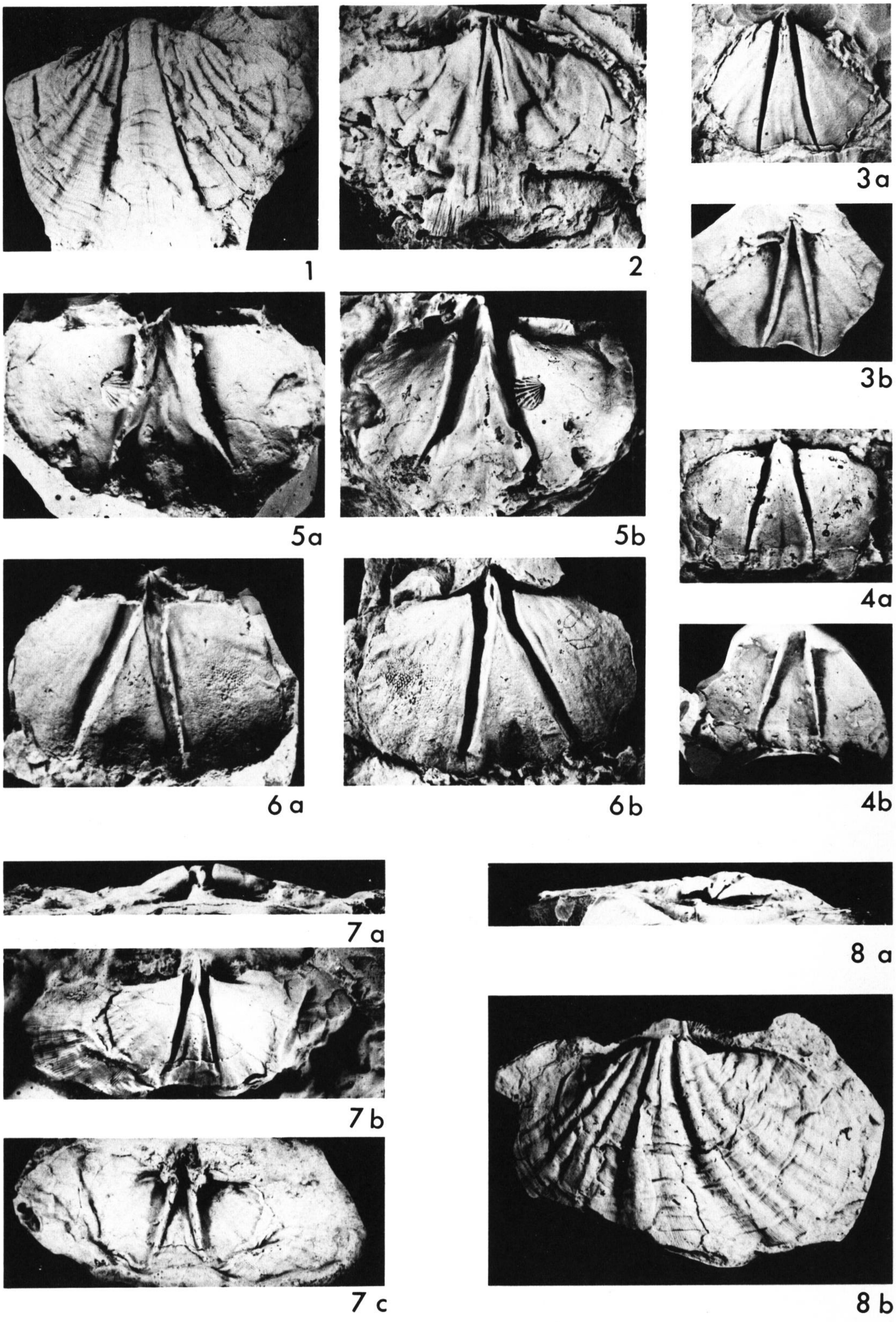

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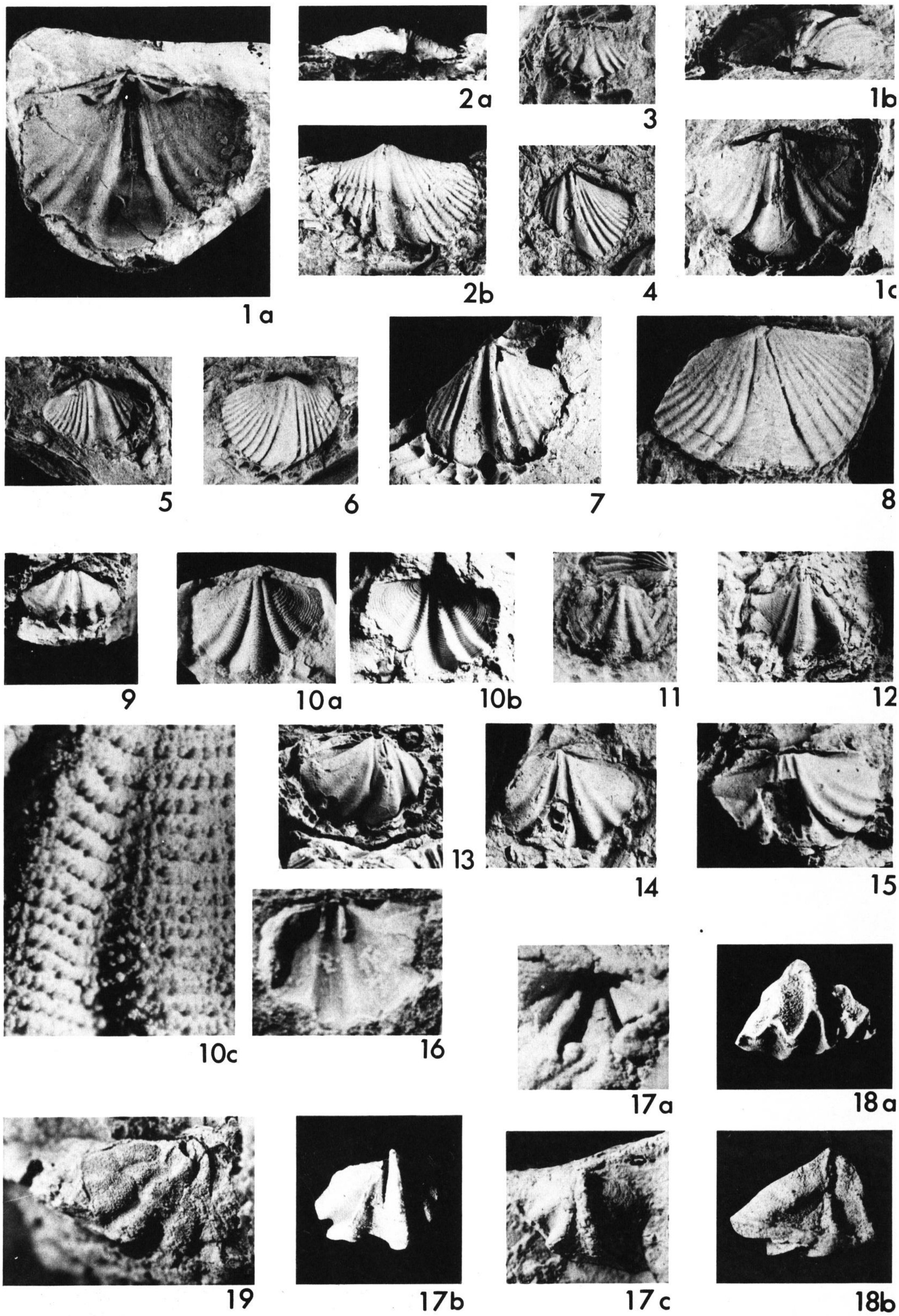

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